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CONCEPT STUDY REPORT
LAUNCH COMPLEX 39 UMBILICAL ARMS

Compiled and Edited

by

J. W. Little

LAUNCH EQUIPMENT BRANCH
LAUNCH SUPPORT EQUIPMENT OFFICE

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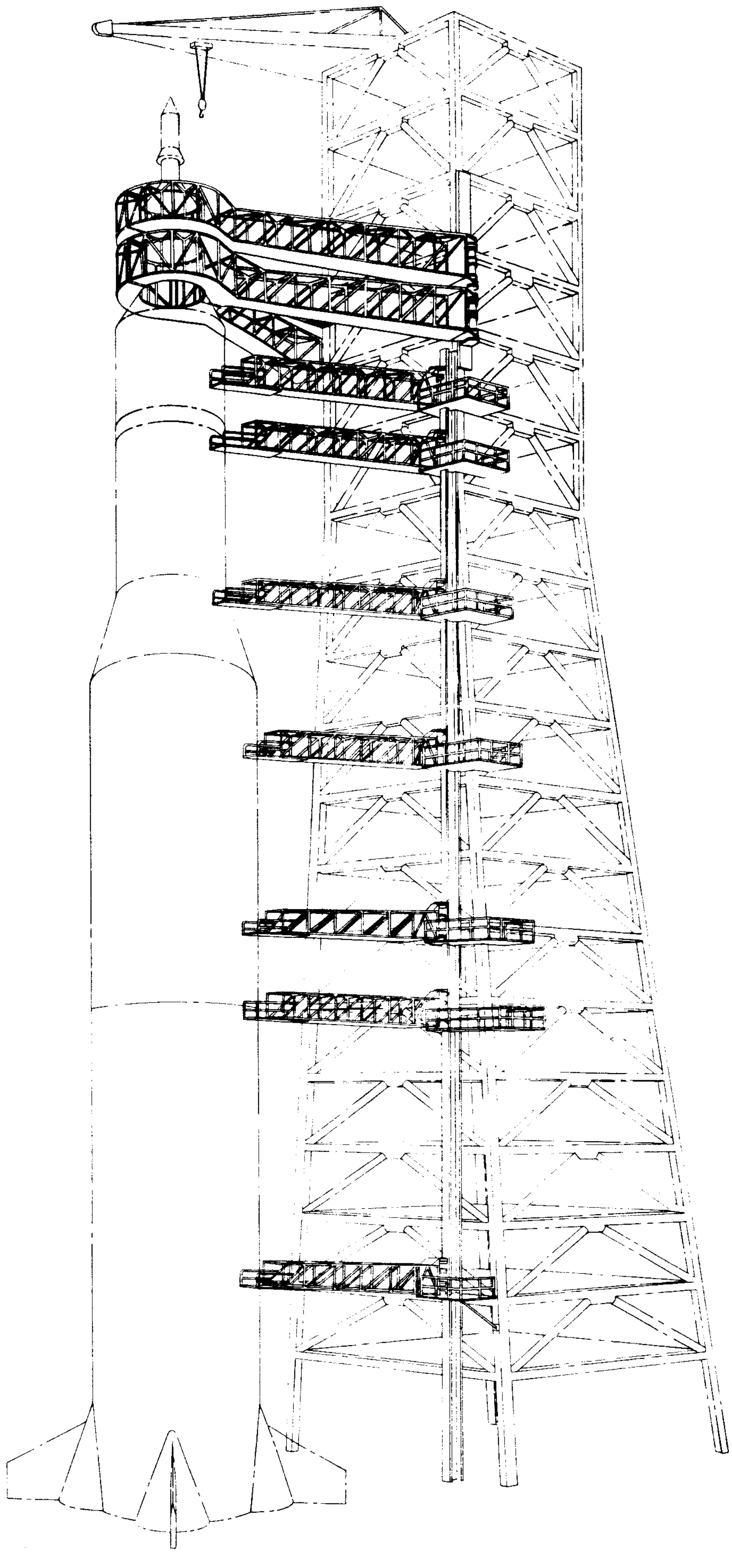

Complex 39 Umbilical Arms

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONCEPT STUDY REPORT

LAUNCH COMPLEX 39 UMBILICAL ARMS

ABSTRACT

This report presents findings and documents recommendations made by the Umbilical Arms Study Group concerning design requirements for the C-5 Umbilical Arms.

The concept study which culminated in this report was initiated by task orders sent out to vendors having responsibility for developing various C-5 Vehicle stages. These task orders requested that qualified representatives be assigned to the Launch Operations Center at George C. Marshall Space Flight Center, Huntsville, Alabama, for the purpose of presenting requirements, planning the development of umbilical systems and coordinating stage umbilical requirements with those of other stages on the vehicle.

Alternate concepts were to be considered and compared for reliability, simplicity, and function.

Present concepts call for approximately eight arms (a varying number of arms are required for different vehicle configurations) to be designed, fabricated and rigged with firing accessories, for mounting on the umbilical tower. During prelaunch servicing,

check-out, and launch, these arms will provide structural support and mobility for the various plumbing and electrical lines linking the vehicle umbilicals with the appropriate ground support equipment.

Mechanisms will be built into the vehicle ends of the arms to provide umbilical connect and remote disconnect. These mechanisms will make possible service line disconnection either prior to vehicle holddown release or after vehicle holddown release and before the vehicle has lifted to a prescribed height above the launch pad. Disconnect mechanisms will be designed in such a manner that they will not prohibit remote reconnect, should this requirement develop.

Consideration had to be given during the study to adaptability of the arms to the vertical assembly building and to a transportable launcher. Coordination was further necessitated by the fact that design and fabrication of the arms has to occur simultaneously with, not following, design and fabrication of the vehicle stages and other ground support equipment.

Design studies have not always led to specific design recommendations; however, in most cases, indicated design parameters or criteria have been established.

Much thought and research has been directed toward the adaptation of previously-proven hardware for the arms. Attention has also been focused around standardization and simplification of design which would promote interchangeability of parts and efficiency of manufacture.

Toward this end, research has included arms pivoting horizontally, either clockwise or counterclockwise around a vertical axis; vertically down around a horizontal axis, by dropping; vertically up around a horizontal axis, by toggle linkage; vertically down around a nonfixed horizontal axis, by means of drop linkage; an arm retracting horizontally along its longitudinal axis; and an arm pivoted about a canted axis to use gravity actuation.

Methods have been considered and the relative merits weighed, for actuating the arms by hydraulic, pneumatic, electrical, mechanical, and gravitational forces.

For purposes of this study, the hydraulically actuated, horizontally pivoting arms are employed; due primarily to a higher degree of past experience with that configuration rather than to faults with the alternate methods. A rotary hydraulic actuator, similar to that previously proven on the Saturn C-1 configuration umbilical arms, has been used for umbilical arm studies.

As in any study of this type, proposals may tend to be altered by later developments and experimentation; however, it is considered that specific quantitative and qualitative data contained in this report is the best available as of August 1, 1962.

Factors contributing to recommendations made by the study group follow within their appropriate areas of the report.

ACKNOWLEDGEMENTS

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SECTION I

INTRODUCTION

This concept study report contains generally an outline of the major configurations considered for design of the C-5 Umbilical Arms for use on the Umbilical Tower of Complex 39 at Cape Canaveral. More specifically, the report outlines parameters and criteria for design and fabrication of a number of retractable umbilical arms, for their associated umbilical disconnect and withdrawal mechanisms, and for their retract systems.

The proposed arms are to be similarly constructed of tubular aluminum trusses. The arms are to be so designed that at lift-off they can be retracted out of the main path of thrust and clear of the worst vehicular drift envelope anticipated. Proposals are presented for various methods of disconnect and withdrawal of umbilical connectors prior to arm retraction. The text of the report is supplemented by illustrations, charts, and tables wherever feasible.

It has not been a function of this report to outline detailed procedures for designing the umbilical arms and disconnects; rather, a definite criteria has been established which will act as a design specification, within which a reasonable amount of leeway is allowed for design of the components.

The following sections contain detailed results of the study. For

calculations supporting various recommendations made by the group, refer to the Appendices following Section XIII.

SECTION II

SUMMARY

In briefly outlining the duties and accomplishments of the Umbilical Arms Study Group, consideration has to be given to the prime problems confronting the group at the outset of the study program. It is the function of this section of the report to summarize these problems.

Briefly stated, the main duty facing the group was to assist the Launch Equipment Branch, Launch Support Equipment Office of Launch Operations Center, in developing a system for servicing and supplying the umbilical requirements of a composite Saturn C-5 vehicle. This practical system concept, which quickly narrowed down to a series of retractable umbilical arms, had to be considered for compatibility with all vehicle stages and indicated a need for careful evaluation from the standpoints of reliability, simplicity and function.

Consideration had to be given to the development of umbilical retract mechanisms that would remove the umbilical systems from the path of vehicle travel. Further complications involved developing retractable arms that would be adaptable to either an "open" or a closed vertical assembly plant. Highly reliable disconnect/withdrawal mechanisms were needed to enable rapid service arm retraction after

lift-off is initiated. Arms attached to the vehicle at lift-off were limited to an absolute minimum.

As an aid in developing a fully adaptable umbilical system, it was desirable that consideration be given to remote reconnection of propellant lines, in the event a decision is made to disconnect and confirm arm retraction start prior to holddown release. For orbital rendezvous missions, remote reconnect is required in order to be ready for launch within the next launch window.

Numerous problems were encountered, such as: (1) deflections and sagging conditions anticipated in the vehicle due to wind, thermal expansion, loads, and tower deflections due to wind; (2) possible variations (drift) in flight path of missile caused by high winds or engine performance, and; (3) protection of umbilical components from effects of exhaust blast impingement and heat. These problems have necessitated, in conjunction with the main areas of the study, a great deal of study leading to development of the presently proposed umbilical arm systems concepts.

SECTION III

GENERAL CONSIDERATIONS

A. INTRODUCTION

This section presents the general problems and background considered in developing an engineering approach to the umbilical arms study. Present indications are that the vehicle and umbilical tower will be mounted on a transporter-launcher base, with the tower being of structural steel construction, incorporating a four-cornered, pyramid-type design.

B. INTERRELATIONS BETWEEN VEHICLE, ARMS, AND TOWER

Design of the tower and arms is determined primarily by the design of the flight vehicle. For example: the height of the vehicle, the number of stages, the serviceability and umbilical requirements of each stage, etc., determine the general tower size, height, and performance capability. Attempts have been made to plan a tower and arms that could accommodate any changes that are likely to be made in the flight vehicle itself. With this adaptability to future vehicles in mind, the side of the tower adjacent to the flight vehicle is designed with a vertical face. This type face permits any particular umbilical arm to be located vertically at almost any altitude, should it be considered necessary to change the location of the umbilical connection on the flight vehicle, or if a change is made in the location of access doors on

the vehicle. It is unlikely that changes to the arm itself would be necessitated by a relocation in altitude, since the skin of the stage being serviced would be essentially parallel to the vertical face of the tower. Relocation of the arm structure would consist primarily of removing bolts securing the arm to the tower, repositioning arms, and reinstalling bolts.

Each arm is basically a fabricated tubular truss, similar to all the other arms, except for length. All arms are to be capable of independent operation by local control and of either independent or interlocked operation by remote control.

C. OVERALL OPERATIONAL PICTURE

The flight vehicle is assembled in the vertical assembly building (VAB), on a transporter-launcher which also carries the umbilical tower. Preflight checks are made and when the vehicle leaves the VAB, it should be in a condition ready for flight, except for arming, final checkout, and propellant loading. The transporter-launcher carrying the flight vehicle and the tower is moved from the VAB via the arming tower to the launch site and propellants pumped aboard. After final countdown, the vehicle is launched, and the transporter with the tower returns to the VAB to be refurbished for reuse.

All umbilical connections are made and checked out in the VAB. During transport, arming, and propellant loading processes, the umbilicals remain connected. Propellant loading takes place through the

umbilicals. Propellant "topping" and boil-off relief are maintained after primary propellant loading. Air-conditioning, electrical connections, and all other umbilical lines are kept active up to disconnect signal. The signal for disconnects may be given just prior to launch, at launch (hold-down release), or in flight. If the signal for disconnect is given prior to launch, it is desirable to require a feedback signal to be made so that actual release may be confirmed. It is also necessary, in this case, to consider the advantages and disadvantages of a reconnect capability, should an abort be ordered after umbilical disconnect and before hold-down release. If disconnect is made at launch or post-launch, utmost reliability must be assured to prevent vehicle flight failure; this reliability can be improved with suitable back-up systems, and minimum hazard designs.

D. BASIC PRESENT DAY ARM THEORY - GENERAL CONSIDERATIONS

Experience acquired on vehicle launches prior to the C-5 will be exploited to insure maximum reliability and performance on the proposed design. Presently used techniques and designs will be given careful consideration. In particular, studies will be made of the experience gained from the launches of the C-1 vehicles from Complex 37. This complex utilizes a four-post launch tower and horizontally-swinging umbilical arms. Presently, three arms supply the umbilical requirements for Complex 37. As viewed from above, the lower arm swings

counterclockwise and the two upper arms swing clockwise. Tests with these arms indicate that application of the horizontal swing arm principal is satisfactory. No arm retraction failures have been reported to date in Marshall Space Flight Center Tests; this provides some justification for continuing with this principal on the Complex 39 launches.

Reliability of the horizontal swing arms depends upon the controlled application of force for the complete period of arm swing. Reliability of the system could be improved by utilizing gravity as the power source for arm retraction, since gravitational force, once unleashed, is not subject to failure.

E. OPERATIONAL THEORY OF UMBILICAL ARMS

Various schemes have been proposed and studied for the purpose of determining optimum operational function for umbilical arms as contemplated for the C-5 vehicle. Illustrations of some of the concepts studied are included in this report. Some of the proposed arms depend upon external power, while others are partially or completely powered by gravity forces. Advantages and disadvantages of the various proposals are tabulated.

In essence, a choice must be made from the available designs to optimize performance and reliability. A simple and highly reliable system is a vertical drop arm, since it required only the action of a triggering device to initiate motion; however, other considerations make it necessary to investigate alternate designs.

The function for any umbilical arm is simple and straightforward. It supports the various electrical, pneumatic, or fuel lines which are connected to the vehicle at the vertical assembly building where check-outs are performed and provides access to the vehicle.

The umbilicals are used to charge the vehicle on the pad. After final checkout, the umbilicals are disconnected from the vehicle upon signal, and the hoses, lines, and plates withdrawn and retracted from the path of the rising vehicle.

F. INTERFACES BETWEEN TOWER, ARMS, AND VEHICLE

The umbilical arms are primarily associated with ground support and launch operations. Umbilical services that these arms carry involve vehicle systems and structure design, manufacture and testing and are primarily associated with vehicle function. From the stand-point of vehicle function, establishment of an optimum interface for design responsibility requires determination of a practical physical location where umbilical arms and services cease to be stage peculiar and can be termed common supply facilities. Stage peculiarity is chosen as the determining factor for the following reasons:

(1) C-5 is essentially a research and development program so vehicle mission and design requirements are subject to continuous review and change.

(2) All umbilical services are governed by vehicle design to a point of common supply and must be continuously coordinated with this design.

(3) All umbilical services to the point of common supply are required for stage test programs prior to launch usage.

(4) In the case of at least one stage, S-IVB, design and hardware carryover possibilities exist which may also be utilized for C-5,

(5) Design and manufacture lead time requirements for stage peculiar portions of umbilical arms and services are set by vehicle design development.

Practical interfaces for arms and services are shown in figure 3-1. For the arm and structure, these are:

(1) The vehicle end of a basic arm structure which may be common for all stages. This is the point where stage peculiarity of arm structure ceases.

(2) The arm mounting face on the tower

For the umbilical services, these are:

(1) The point of flex-to-solid line connection at the outboard end of the arm.

(2) The point of flex line connection to the tower connector plate at the face of the tower. This is the closest point to the vehicle where stage peculiarity begins to disappear.

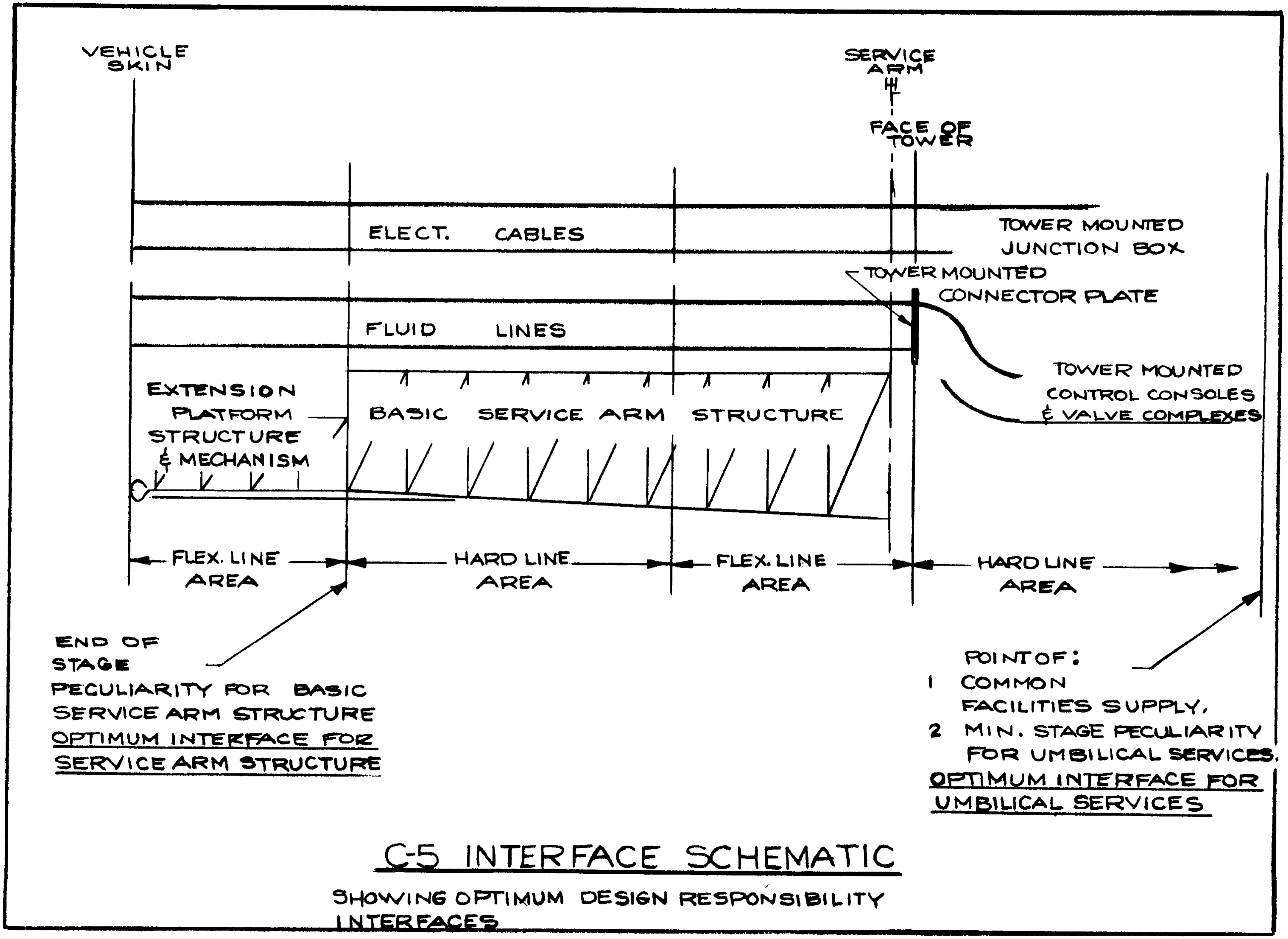

Figure 3-1. C-5 Interface Schematic

(3) The point of connection of valve complexes and control consoles to common supply lines on the tower. Stage peculiarity has almost entirely disappeared at this point.

The electrical cabling optimum interface is the tower mounted J box.

The vehicle skin, or the upstream side of the ground half umbilical plate as defined by present contracts, is not considered a practical interface because of inherent design and manufacturing coordination difficulties.

SECTION IV

VEHICLE AND STAGE DATA AND CONFIGURATION

A. INTRODUCTION

The C-5 vehicle for different mission configurations is composed of the following stages:

1. Stage I Booster, S-IC.
2. Stage II, S-II.
3. Stage III, S-IVB.
4. Instrument Unit.
5. Apollo.
   a. Service Module.
   b. Command Module.
   c. Escape System.
6. Lunar Excursion Module (LEM) and a Nuclear Stage (S-N).

These stages will be in various combinations as indicated by figure 4-1.

B. STAGE INFORMATION

1. S-IC Booster.

The general configuration of the S-IC stage is shown in figure 4-2. Most launch site services to the S-IC stage are provided through connections between the aft end of the stage and the launcher deck and are not of consideration in the design of the umbilical arms.

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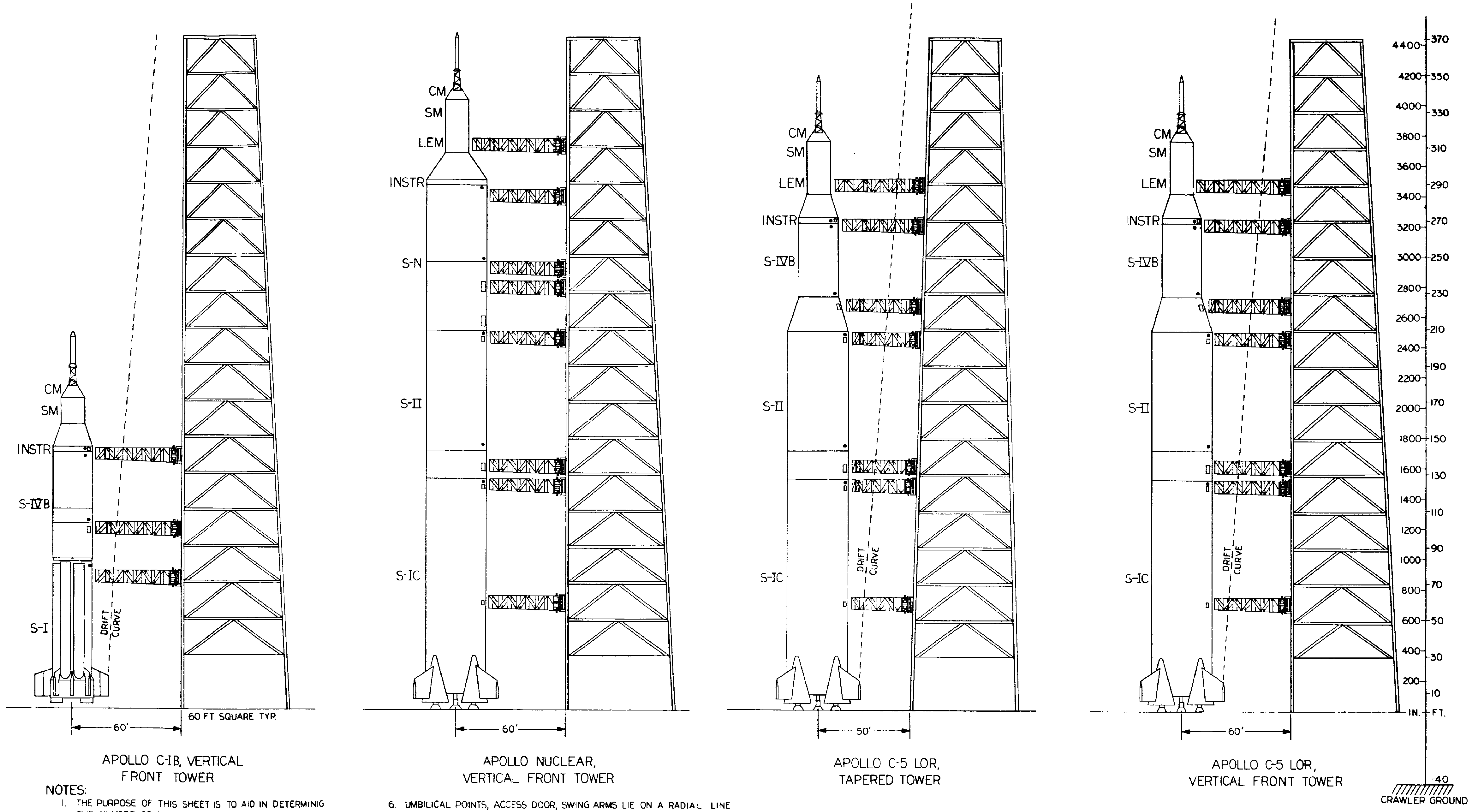

NOTES:

1. THE PURPOSE OF THIS SHEET IS TO AID IN DETERMINIG THE NUMBER OF ARMS NEEDED, THEIR STATION VARIATIONS, AND ILLUSTRATE THE DRIFT CURVES APPLIED TO TOWERS WITH VERTICAL AND TAPERED FACES.
2. FIN TIP RADIUS ILLUSTRATED 378 IN. ON S-IC AND 245 IN. ON S-I.
3. LEGEND: •UMBILICAL CONNECTION, ▯ ACCESS DOOR
4. C-5 DRIFT CURVE PER AEROBALLISTICS 10 MARCH 62, C-1B DRIFT CURVE SAME AS C-1 BLOCK II.
5. FLIGHT DIRECTION IS TOWARD THE VIEWER AND NORTH IS TO THE RIGHT.
6. UMBILICAL POINTS, ACCESS DOOR, SWING ARMS LIE ON A RADIAL LINE FROM VEHICLE CENTERLINE 73° NORTH OF FLIGHT DIRECTION FOR ALL STAGES EXCEPT S-1 WHICH IS 58°.
7. LAUNCHER DECK SHOWN AT VEHICLE STATION +4.0 FOR C-5 AND -26.25 FOR C-1B. SCALE AT RIGHT MEASURES FROM LAUNCHER DECK.
8. SOURCE OF STAGE DIMENSIONS: C-5 LOR 80299 7-16-62; C-1B 80291 7-12-62; S-N M-LOD-DL; INSTR UNIT J10M-040008
9. APOLLO ACCESS ARMS NOT SHOWN.

Figure 4-1. Complex 39 Configurations

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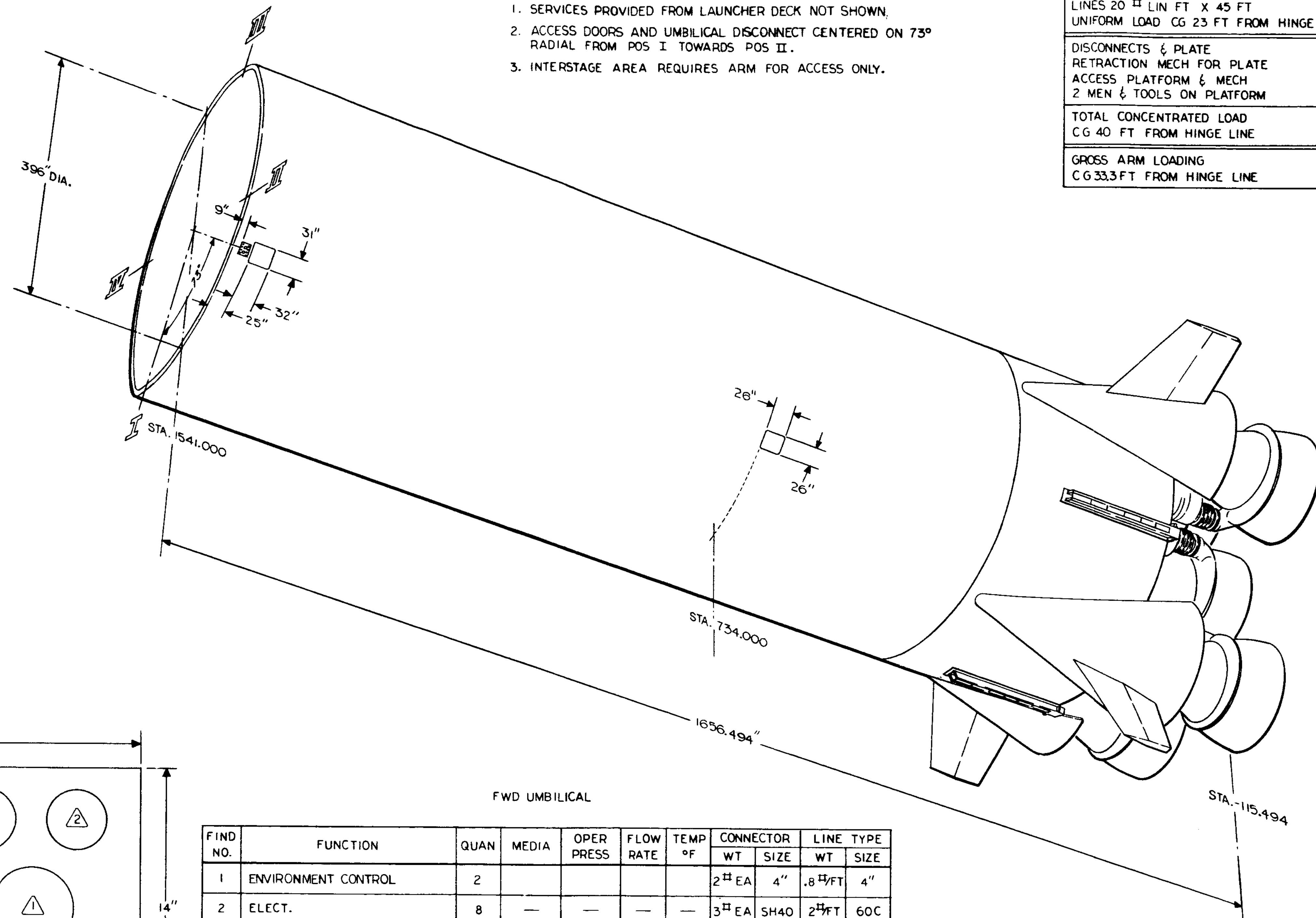
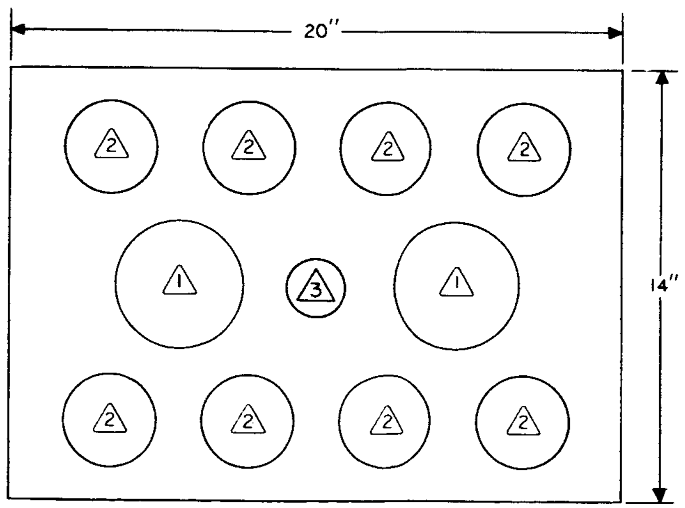
NOTES:
1. SERVICES PROVIDED FROM LAUNCHER DECK NOT SHOWN.
2. ACCESS DOORS AND UMBILICAL DISCONNECT CENTERED ON 73° RADIAL FROM POS I TOWARDS POS II.
3. INTERSTAGE AREA REQUIRES ARM FOR ACCESS ONLY.

FWD UMBILICAL ARM LOADS	
LINES 20 # LIN FT X 45 FT UNIFORM LOAD CG 23 FT FROM HINGE LINE	900 #
DISCONNECTS & PLATE RETRACTION MECH FOR PLATE ACCESS PLATFORM & MECH 2 MEN & TOOLS ON PLATFORM	180 # 200 # 300 # 700 #
TOTAL CONCENTRATED LOAD CG 40 FT FROM HINGE LINE	1380 #
GROSS ARM LOADING CG 33.3 FT FROM HINGE LINE	2280 #





FWD UMBILICAL AREA

FWD UMBILICAL

FIND NO.	FUNCTION	QUAN	MEDIA	OPER PRESS	FLOW RATE	TEMP °F	CONNECTOR WT	CONNECTOR SIZE	LINE TYPE WT	LINE TYPE SIZE
1	ENVIRONMENT CONTROL	2					2 # EA	4"	.8 #/FT	4"
2	ELECT.	8	—	—	—	—	3 # EA	SH40	2 #/FT	60C
3	DISCONNECT ACTUATION	1	AIR	UNDETER-MINED	NEG	AMB-IENT	NEG	3/8	NEG	3/8

Figure 4-2. S-IC Configuration

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However, aft end service requirements are tabulated for reference in Section V. As indicated, aft end services include all propellant lines.

a. Intertank Access.

The S-IC stage is provided with two hatches for access to the cavity between the LOX tank (upper) and RP-1 tank. One door is located on the umbilical entry radial (73 degrees north of the flight direction), the other is located diametrically opposite. A service arm equipped with outlets for work lights, power tools, and telephone jacks will be required to line up with the 73-degrees-north-of-flight access hatch. Umbilicals services required for this area are unsettled.

b. Forward Umbilicals.

The S-IC forward umbilicals will provide access and such umbilical services as cannot be carried efficiently to the aft end of the stage. The hatch in the upper skirt provides access to the S-IC forward cavity. The umbilical connector is located above this door as indicated. This umbilical carries air-conditioning and electrical services as described in Section V.

2. S-II Stage.

The general configuration of the S-II stage is shown in figure 4-3. The stage mounts directly on top of the S-IC stage.

Five LH_2 engine feed lines are located externally around the stage circumference.

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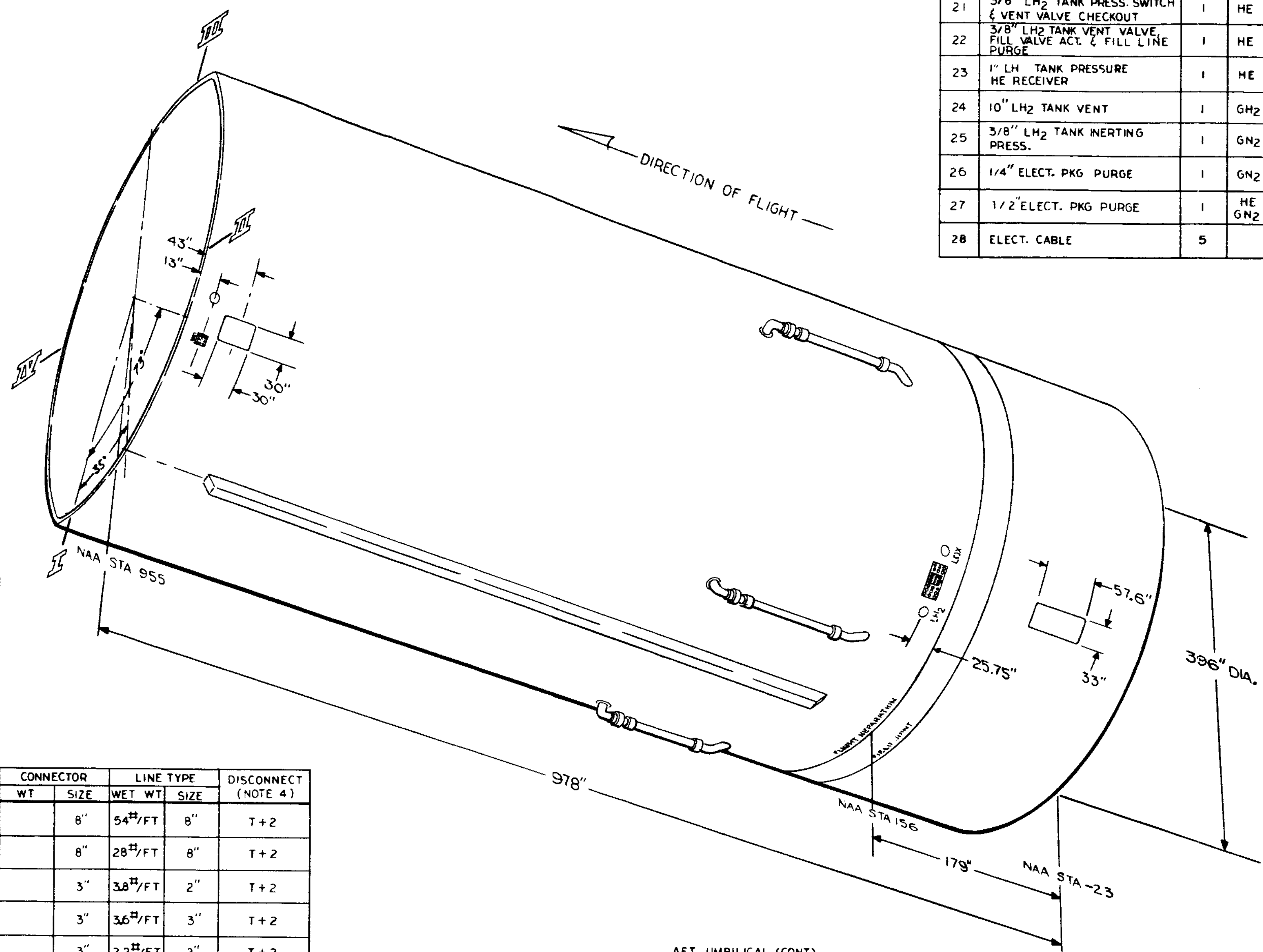
FWD UMBILICAL

FIND NO.	FUNCTION	QUAN	MEDIA	OPER PRESS.	FLOW RATE	TEMP °F	CONNECTOR WT	CONNECTOR SIZE	LINE TYPE WET WT	LINE TYPE SIZE	DISCONNECT (NOTE 4)
21	3/8" LH_2 TANK PRESS. SWITCH & VENT VALVE CHECKOUT	1	HE	25-40	N.A.	AMB		3/8"	.2#/FT	3/8"	T-30
22	3/8" LH_2 TANK VENT VALVE, FILL VALVE ACT. & FILL LINE PURGE	1	HE	750	N.A.	AMB		3/8"	.2#/FT	3/8"	T+4
23	1" LH TANK PRESSURE HE RECEIVER	1	HE	3000	N.A.	-250		1"	1.6#/FT	1"	T-30
24	10" LH_2 TANK VENT	1	GH_2	33 1/2-37	N.A.	-423		10"	16#/FT	10"	T+2
25	3/8" LH_2 TANK INERTING PRESS.	1	GN_2	3-5	N.A.	N.A.		3/8"	.2#/FT	3/8"	(NOTE 5)
26	1/4" ELECT. PKG PURGE	1	GN_2	3-4	N.A.	N.A.		1/4"	.16#/FT	1/4"	T-30
27	1/2" ELECT. PKG PURGE	1	HE GN_2	60	N.A.	N.A.		1/2"	.37#/FT	5/8"	T+2
28	ELECT. CABLE	5					2.4#/FT PER CABLE		12#/FT		T+4

TOTAL 30.8#/FT
USE 44 #/FT

AFT UMBILICAL ARM LOADS	NOTE 6 CONDITION A	NOTE 6 CONDITION B
LINES, 150#/LIN FT X 45 FT LOX IN LINE	5670#	5670# 1080#
TOTAL MAX UNIFORM LINE LOAD C G 21' FROM TOWER	5670#	6750#
DISCONNECTS & PLATE LOX & LH_2 DISCONNECTS MECH RETRACTION MECH FOR PLATE ACCESS PLATFORM & MECH 3 MEN ON PLATFORM	300# 1600# 200# 300# 600#	300# 1600# 200# 300#
TOTAL CONCENTRATED LOAD C G 40' FROM TOWER	3000#	2400#
GROSS ARM LOADING C G FROM TOWER	8670# 27.5 FT	9200# 26.1 FT

6. LOADS ON THE UMBILICAL ARM WILL BE IMPOSED BY TWO CONDITIONS
   A. MEN ON THE ARM AND NO FLUID (LOX & LH_2) IN LINES.
   B. FLUID (LOX & LH_2) IN THE LINES AND NO MEN ON THE ARM.



FWD UMBILICAL ARM LOADS	
WT OF LINES 44# LIN FT X 45 FT C G 21' FROM TOWER	1980
DISCONNECTS & PLATE RETRACTION MECH. ACCESS PLATFORM & MECH 3 MEN ON PLATFORM	100 100 200 600
TOTAL CONCENTRATED LOAD C G 40' FROM TOWER	1000
GROSS ARM LOADING C G 27.4' FROM TOWER	2980

AFT UMBILICAL

	FIND NO.	FUNCTION	QUAN	MEDIA	OPER PRESS.	FLOW RATE	TEMP °F	CONNECTOR WT	CONNECTOR SIZE	LINE TYPE WET WT	LINE TYPE SIZE	DISCONNECT (NOTE 4)	
	1	8" LOX FILL	1	LOX	125	5000 GPM	-297		8"	54#/FT	8"	T+2	
	2	8" LH_2 FILL	1	LH_2	125	10000 GPM	-423		8"	28#/FT	8"	T+2	
	3	3" GAS GEN. COOLDOWN, LOX	1	LOX	40 MAX.	BLEED LINE	-297		3"	3.8#/FT	2"	T+2	
	4	3" GAS GEN. COOLDOWN, LH_2	1	LH_2	40 MAX.	BLEED LINE	-423		3"	3.6#/FT	3"	T+2	
	5	3" ENGINE COMPART. PURGE	1	GN_2	60	N.A.	-160		3"	2.2#/FT	2"	T+2	
	6	1 1/4" LOX PUMP SEAL BLEED	1	LOX	130 MAX.	BLEED LINE	-297		1 1/4"	2.4#/FT	1 1/4"		
	7	1/2" ENG HE. BOTTLE FILL	1	HE	2700	N.A.	-250 ± 50		1/2'	.3#/FT	3/8"	T-30	
	8	1/2" GH_2 BOTTLE VENT CONTROL	1	HE	400	STATIC	0-70		1/2'	.2#/FT	3/8"	T-30	
	9	1/2" TURBO PUMP PURGE	1	HE	75	N.A.	0-70		1/2"	.37#/FT	3/4"	T-30	
	10	1 1/2" GH_2 VENT VALVE & RELIEF DRAIN	1	GH_2	800 ± 25	N.A.	-250 ± 50		1 1/2"	1.6#/FT	1 1/2"	T-30	
	11	5/8" GH_2 BOTTLE FILL	1	GH_2	1150 ± 25	N.A.	-250 ± 50		5/8"	.8#/FT	1"	T-30	
	12	1" LH_2 PUMP SEAL BLEED	1	LH_2	100 MAX.	BLEED LINE	-423		1"	1.2#/FT	1"	T+2	
	13	1/4" ELECT. PKG & PURGE PRESS.	1	GN_2	3-4	N.A.	N-A		1/2"	.16#/FT	1/2"	T-30	
	14	3/8" LOX TANK PRESS. SWITCH & VENT	1	HE	0-40	N.A.	AMB		3/8"	.2#/FT	3/8"	T-30	
	15	1" LOX TANK PRESSURE HE RECEIVER	1	HE	3000		-250		1"	1.4#/FT	1"	T-30	
1	16	3/8" LOX TANK VENT VALVE, LOX TANK FILL VALVE ACT. & LOX FILL LINE PURGE	1	HE	750	N.A.	AMB		3/8"	.2#/FT	3/8"	T+4	1
	17	ELECT. CABLE	18					2.4#/FT PER CABLE		43.2#/FT		T+4	

AFT UMBILICAL, (CONT)

FIND NO.	FUNCTION	QUAN	MEDIA	OPER PRESS.	FLOW RATE	TEMP °F	CONNECTOR WT	CONNECTOR SIZE	LINE TYPE WET WT	LINE TYPE SIZE	DISCONNECT (NOTE 4)
18	1/2" ELECT. PKG PURGE	1	HE GN_2	60	N.A.	AMB		1/2'	.2#/FT	1/2"	T+2
19	3/8" LOX TANK POSITIVE PRESSURE	1	GN_2	3-5	N.A.	N.A.		3/8"	.2#/FT	3/8"	(NOTE 5)
20	1" GH^2 START TANK VENT	1	GH_2	800	2.5#/SEC	-250 ± 50		1"	.8#/FT	1"	

TOTAL 145#/FT
USE 150#/FT

NOTES:
1. SYMBOL 1 SERVICES WILL BE REMOVED FROM AFT PLATE AND INCORPORATED INTO FWD PLATE IF AFT PLATE IS NOT TO BE A FLY-AWAY CONNECTION.
2. ALL UMBILICAL AND ACCESS DOORS PLACED ON 73° RADIAL FROM POSITION I TOWARD POSITION II.
3. FOR DETAIL OF UMBILICAL AREA, SEE FIGURE 5-4.
4. ENGINE START T=O TIME IN SECONDS.
5. MAY NOT NEED TO BE CONNECTED AT LAUNCH PAD.

Figure 4-3. S-II Configuration

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The S-II stage utilizes a cryogenic propulsion system. The LH_2 tank is forward and LOX tank, aft. The LOX tank vent is located opposite the oxygen supply disconnect so that an atmospheric vent for this tank can be located in a relatively safe area.

a. Aft Umbilical and Access Location.

Aft umbilical services, as described in Section V, are located so as to provide no interference with the aft interstage flight separation.

The location of the aft service disconnects covers an area approximately three feet high and nine feet wide. The vehicle lines terminate at the disconnects that are positioned parallel to the 73-degree radial line.

The access door which provides entrance to the S-II engine compartments (aft cavity) is located directly below the aft umbilical disconnect panel.

b. Forward Umbilical and Access Location.

Forward umbilical services, as described in Section V, terminate in connector panels, located approximately on the 73-degree radial, directly above the lower umbilical area.

The access door which provides entrance to the S-II forward cavity, is located below the forward umbilical connector panels and on the 73-degree radial.

3. S-IVB Stage.

The general configuration of the S-IVB stage is shown in figure 4-4. The S-II interface is at the aft end of the stage and the instrument unit interface is at the forward end of the stage.

The S-IVB utilizes a cryogenic propulsion system. The LH_2 fuel tank is located forward and the LOX tank is aft. The cylindrical portion of the tank skin consists of machine milled, aluminum waffle skin. Bulkheads are of the same material, but have been chemically etched. The entire inner surface of the LH_2 tank, is insulated. The maximum normal external load capacity of the unpressurized tank is 0.5 psi.

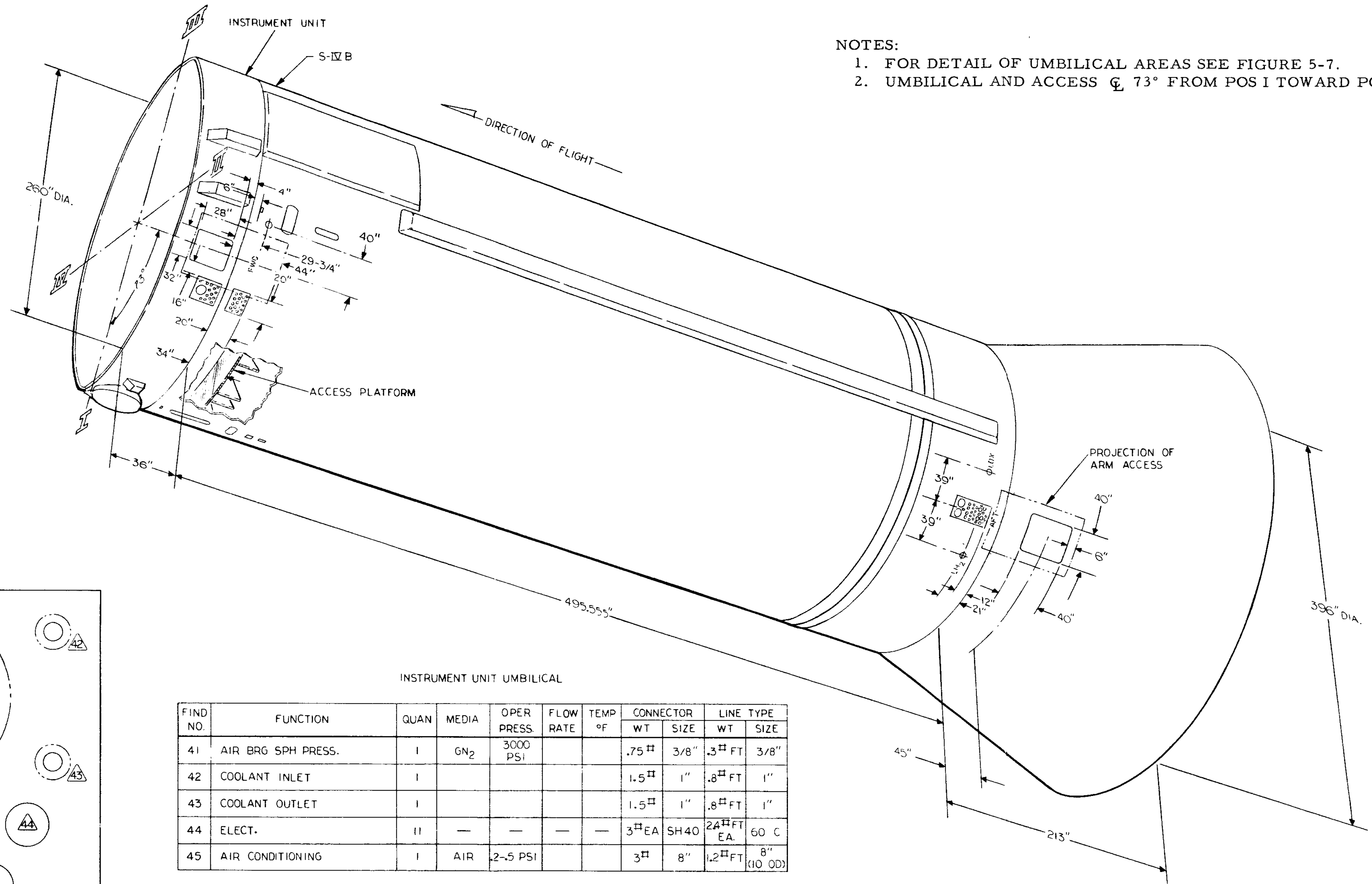
Forward skirt, aft skirt and interstage vehicle portions are of conventional skin and stringer construction. The thrust structure is a cone of conventional skin and stringer construction bolted to an attach angle on the aft bulkhead.

a. Aft Umbilical and Access Location.

The aft umbilical services, as defined in Section V, extend from the stage through connector panels located above the flared interstage interface. The LOX and LH_2 connections will be parallel to and centered about the 73-degree radial plane.

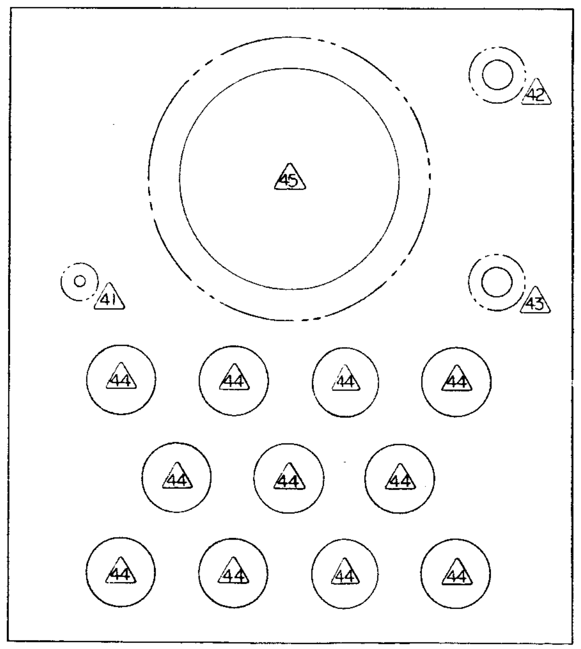
The vehicle panel containing the air-conditioning, pneumatic, electrical, and hypergolic connections is centered between the

NOTES:
1. FOR DETAIL OF UMBILICAL AREAS SEE FIGURE 5-7.
2. UMBILICAL AND ACCESS ℄ 73° FROM POS I TOWARD POS II.



INSTRUMENT UNIT UMBILICAL

FIND NO.	FUNCTION	QUAN	MEDIA	OPER PRESS.	FLOW RATE	TEMP °F	CONNECTOR WT	CONNECTOR SIZE	LINE TYPE WT	LINE TYPE SIZE
41	AIR BRG SPH PRESS.	1	GN_2	3000 PSI			.75#	3/8"	.3# FT	3/8"
42	COOLANT INLET	1					1.5#	1"	.8# FT	1"
43	COOLANT OUTLET	1					1.5#	1"	.8# FT	1"
44	ELECT.	11	—	—	—	—	3# EA	SH40	24# FT EA.	60 C
45	AIR CONDITIONING	1	AIR	.2-.5 PSI			3#	8"	1.2# FT	8" (10 OD)



INSTRUMENT UNIT UMBILICAL AREA

Figure 4-4. S-IVB Configuration

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propellant connections at the same vertical location. The lower umbilicals are located and clustered in the stage as tabulated and shown in Section V. The aft cavity access door is located in the flared aft interstage, below the flared interstage separation plane.

b. Forward Umbilical and Access Location.

The forward umbilical services, as defined in Section V, extend from the stage through connector panels located on the 73-degree radial.

The gaseous hydrogen vent panel is located across the 73-degree radial from the electrical panel. All umbilical skin fittings are parallel to the 73-degree radial plane. Upper umbilicals are located and clustered as tabulated and shown in Section V.

Access is provided to the forward cavity through an access door located in the instrument unit as indicated. Brackets, or hard points for brackets, will be provided in the S-IVB forward skirt to support a removable catwalk located below the forward end of the stage (the instrument unit field splice).

4. Instrument Unit.

The guidance for the S-IVB and all stages beneath is provided by an instrument unit mounted to the forward interface of the S-IVB. The instrument unit may be cylindrical or conical, depending on the diameter of the stage above the S-IVB. If the stage requires a conical

adapter to mate to the S-IVB, then the lower part of the adapter cone will be the instrument unit. If the Apollo Service Module should be the stage above the instrument unit, the cylindrical instrument unit will be as illustrated in figure 4-4. The umbilicals are located as indicated so that they are above those umbilicals of the S-IVB and may be handled with a common mechanism. A tabulation of instrument unit umbilical services is given in Section V. Clustering is shown in figure 4-4.

5. Apollo Spacecraft.

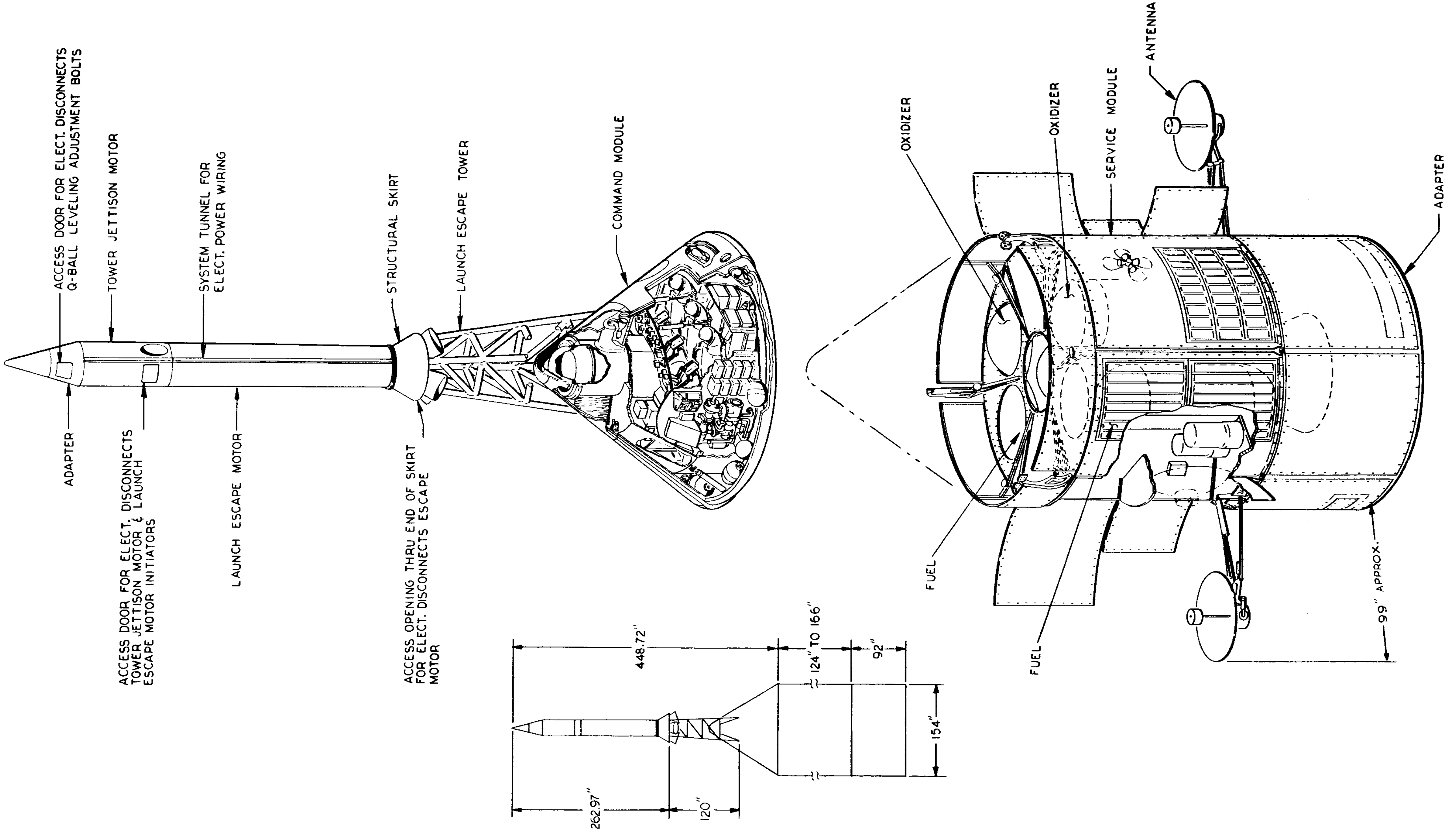
The Apollo Spacecraft consists of a Service Module (S/M), a Command Module (C/M), and a Launch Escape System, as indicated in figure 4-5.

a. Service Module.

The Service Module contains propellant tanks for the service propulsion system and reaction control motors, space radiators, cryogenic tanks, antennas, service propulsion motor, electrical power generating system, and attaching mechanisms.

b. Command Module.

The Command Module is a cone-shaped unit divided into three sections: forward compartment, crew compartment and aft compartment.



NOTES:
1. COMMAND MODULE HAS BEEN ROTATED IN RESPECT TO SERVICE MODULE FOR CLARITY.

Figure 4-5. Apollo Configuration

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The Command Module houses the astronauts, environmental control systems, controls, reaction control motors and tanks, navigation equipment, and waste disposal systems.

A personnel hatch is provided in the crew compartment.

c. Launch Escape System.

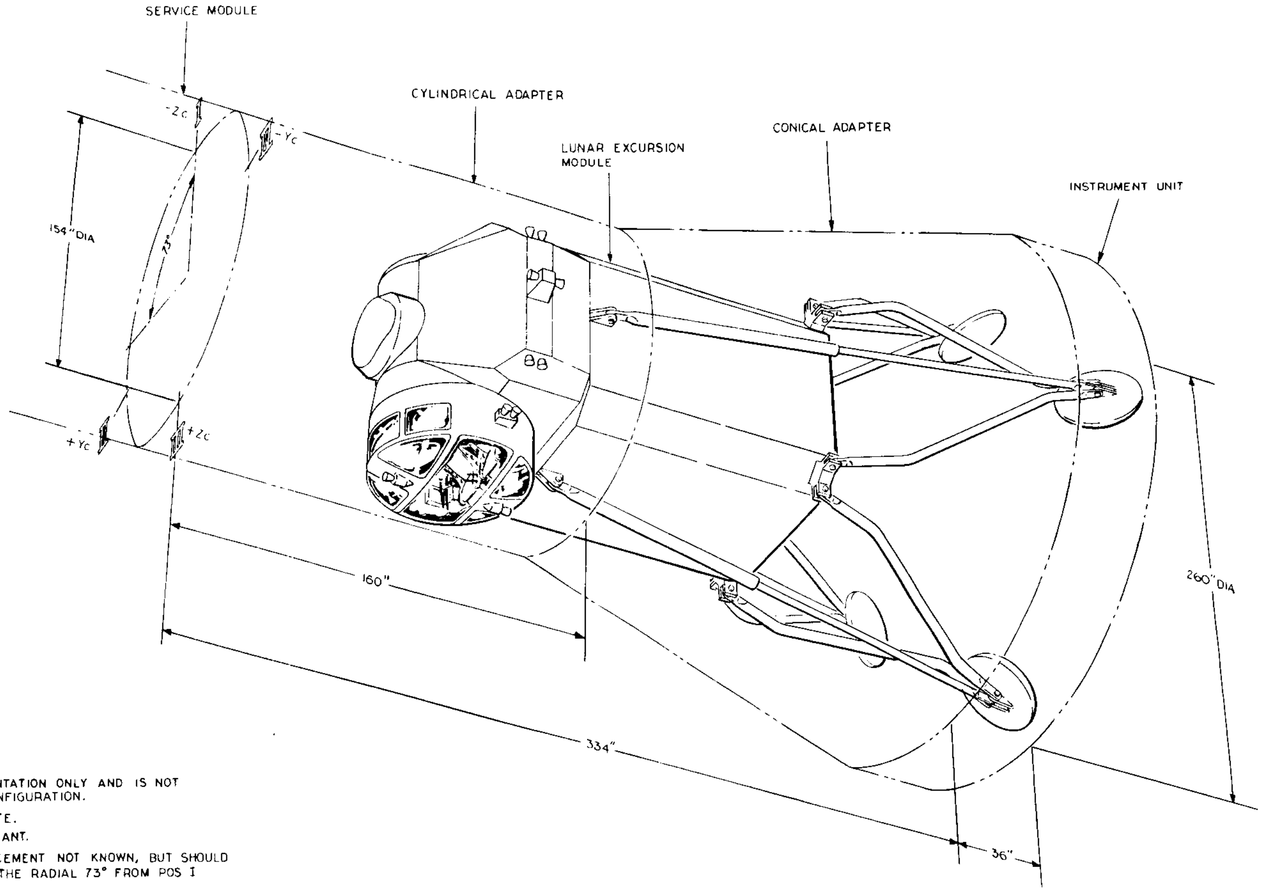
The Launch Escape System consisting of a launch escape tower, launch escape motor, and adapter is mounted atop the Command Module.

6. Future Stages.

a. Lunar Excursion Module.

During preparation of this report, the National Aeronautics and Space Administration made a decision to employ a Lunar Excursion Module (LEM) with a two-man crew to land on the surface of the moon. The LEM would replace the previously conceived R-2 stage. The exact configuration of the LEM is not known at this time; however, the module would probably bear a resemblance to the configuration illustrated in figure 4-6.

An adapter will be required below the Apollo Service Module to incorporate the LEM and to mate with the instrument unit above the S-IVB. The exact dimensions of this adapter are not presently known, but it is likely to result in a shorter C-5 vehicle configuration than would be possible with the previously proposed



NOTES:

1. THIS DRAWING IS FOR GENERAL ORIENTATION ONLY AND IS NOT INTENDED TO REPRESENT A FIRM CONFIGURATION.
2. ADAPTER LENGTHS ARE APPROXIMATE.
3. LEM VIEWED FROM FIN III - IV QUADRANT.
4. ACCESS DOORS AND UMBILICAL PLACEMENT NOT KNOWN, BUT SHOULD BE SERVED BY AN ARM PLACED ON THE RADIAL 73° FROM POS I TOWARD POS II.

Figure 4-6. Lunar Excursion Module

R-2/Apollo combination.

Umbilical and access requirements for the LEM are not detailed at this time. Access to the module on the launch pad will, of necessity, be made through a hatch in the adapter below the Apollo Service Module. Umbilical connections to the LEM would probably be manually serviced, with no connections maintained between the LEM and the umbilical tower at the time of the launch.

b. Nuclear Stage (S-N) and RIFT.

The Nuclear Stage (S-N), and its test bed version, RIFT, obtain propulsion by heating liquid hydrogen, vaporizing, and expelling hydrogen gas at high temperatures and pressures using a nuclear reactor as the heat source.

Provisions must be made in the design of Complex 39 to accommodate both stages, in order that expensive conversions in facilities are not required at a later date. Due to the classified nature of much of the RIFT and S-N project, only unclassified configuration data is supplied in this report to allow sizing of umbilical tower and ground facilities.

Both RIFT and S-N are the same size, as indicated in figure 4-7. The umbilical locations and access doors will be approximately as shown and are indicated so that placement of service arms can be considered.

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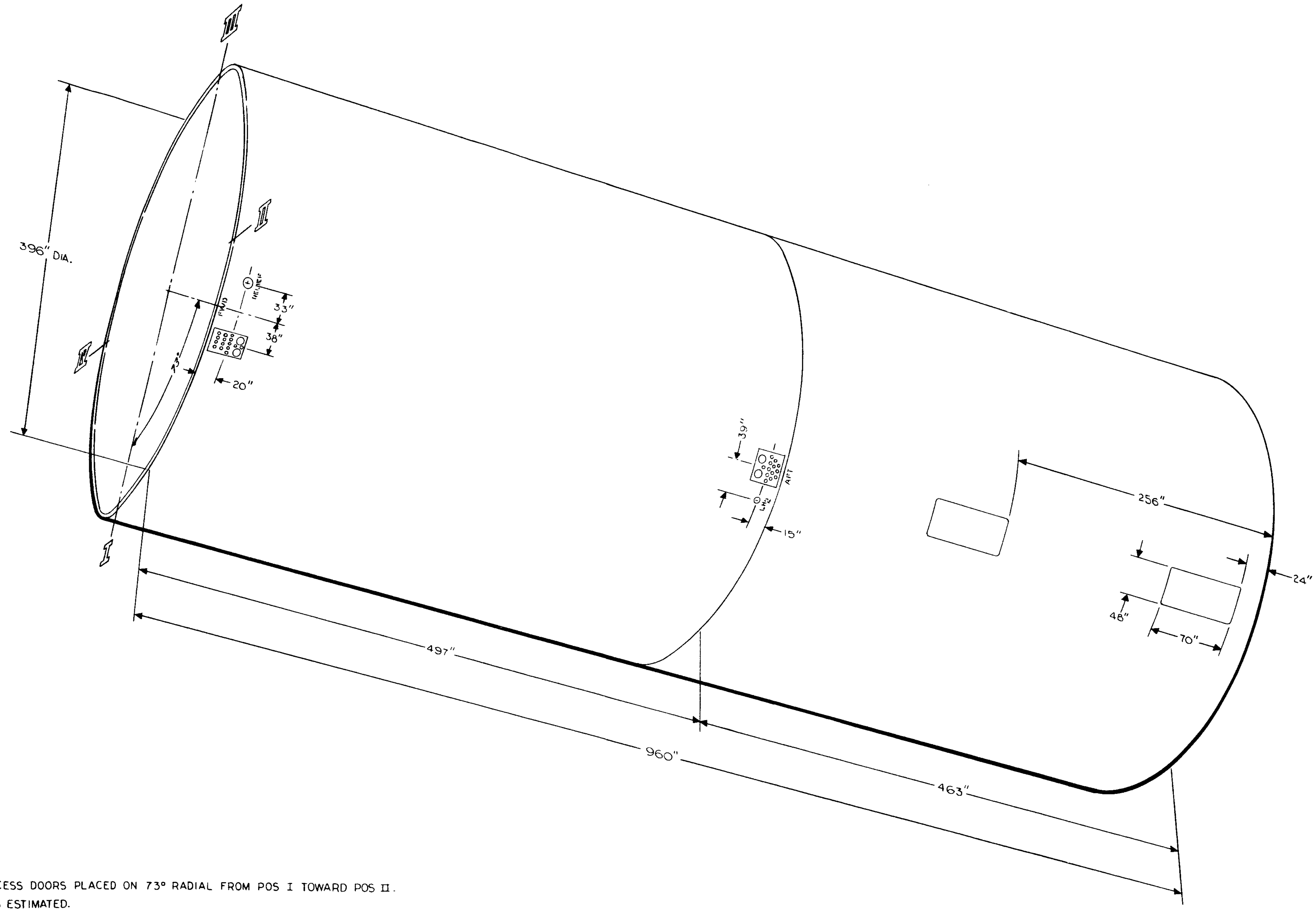

NOTE:

1. ALL UMBILICAL & ACCESS DOORS PLACED ON 73° RADIAL FROM POS I TOWARD POS II.
2. UMBILICAL LOCATIONS ESTIMATED.

Figure 4-7. S-N Configuration

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The actual umbilical services required are not known at this time. They are expected to be similar to those for the S-II stage, with the exception that LOX is not needed. The use of hypergolic attitude control and ullage rockets may require hypergolic umbilicals similar to those of the S-IVB to be added.

C. STAGE AND GROUND HALF UMBILICAL CONNECTION

All vehicle systems requiring umbilicals running from the C-5 stages to ground sources may require connectors, most of which will be located at the vehicle skin. Except for propellant lines and certain vents in all stages except Apollo, these will be collected in common panels and carrier plates. The ground-side carrier plates may be magnesium castings, cored and faced to receive and retain the ground side connectors. Disconnect actuation for the ground side carrier plates shall be accomplished by redundant systems. Primary system disconnect may be accomplished by pneumatic rams integral in the carrier plate casting, pushing off from the vehicle structure. A hydraulic-pneumatic system will be used with an arm supported ram for secondary backup. Tertiary backup may be provided by a mechanical, lever push-off device actuated by stage-arm differential motion.

S-II and S-IVB propellant line connectors may be independent of the common carrier plates. LH_2 and LOX umbilicals are used to purge, fill, top, and drain the vehicle stages.

1. Vehicle Half Umbilical Connections.

LH_2 and LOX vehicle half connectors will incorporate a pneumatically-actuated valve which shall be closed before purging and disconnect. In case of pneumatic failure, the valve will always return to a closed position. The vehicle coupling will incorporate a surface which will seal upon seating with the ground half prior to opening of the ground half of the umbilicals.

Vehicle half air-conditioning connectors will be flush, open type for which no shut-off valves are required.

Vehicle pneumatic connectors will be self sealing, poppet type, quick, disconnect nipples, capable of being locked to by the ground half of the connector. Check valves will be required down-stream (into vehicle) to prevent dumping of gases in case of malfunction of the self-sealing disconnect.

All electrical connections will be standardized within the limits of No. 40 shell size.

For S-IVB, the hypergolic system connectors will be self sealing, poppet type, quick, disconnect nipples, with the exception of the fuel and oxidizer tank vent connections which will remain open after disconnect. The nipples shall be capable of being locked to by the ground half of the connectors. Materials used will be compatible for a hypergolic system.

For S-II and S-IVB, the hydrogen vent connection may be

flush type and if required, be provided with a thrust negating door which will close and latch upon ground half disconnect.

2. Ground Half Umbilical Connections.

LH_2 and LOX ground half connectors (figure 4-8) may be insulated couplings which are sealed by seating to the surface of the vehicle connector. Each connector will be locked to the vehicle. The connection may be surrounded by a sleeve that is purged with low-pressure helium, to prevent liquid air condensation on the coupling if such is required. The quantity of purge gas will be sufficient to maintain an inert atmosphere within anticipated leakage rates. Vehicle design should be such as to permit addition of remote reconnecting propellant loaders at a future date. See Appendix A for principles of remote reconnection.

The air-conditioning ground umbilical will be an open type sealed against the vehicle side connector and held in place by the umbilical carrier.

The pneumatic ground connections will be self sealing and self locking quick disconnect couplings. Couplings capable of condensing air will be surrounded by a sleeve that is purged with low pressure helium to prevent liquid air condensation on the coupling.

All electrical ground half connectors will be standardized within the limits of shell size 40 connectors.

For S-IVB, the hypergolic ground side connectors will be

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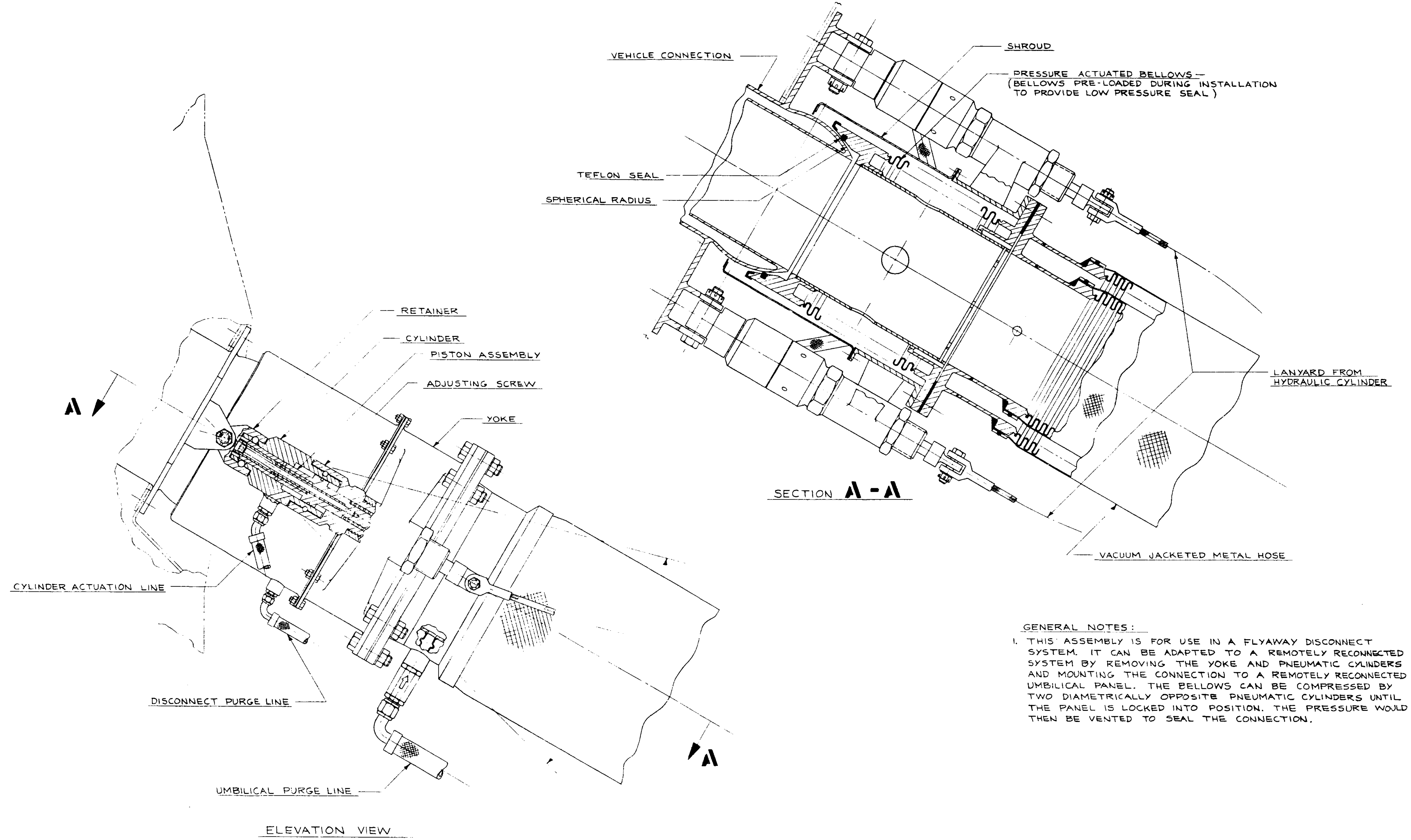

Figure 4-8. Propellant Umbilical Disconnect

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similar to the pneumatic ground side connectors.

For S-II and S-IVB, the hydrogen vent ground half connectors (figure 4-9) will be self sealing, flush type, locked to the vehicle.

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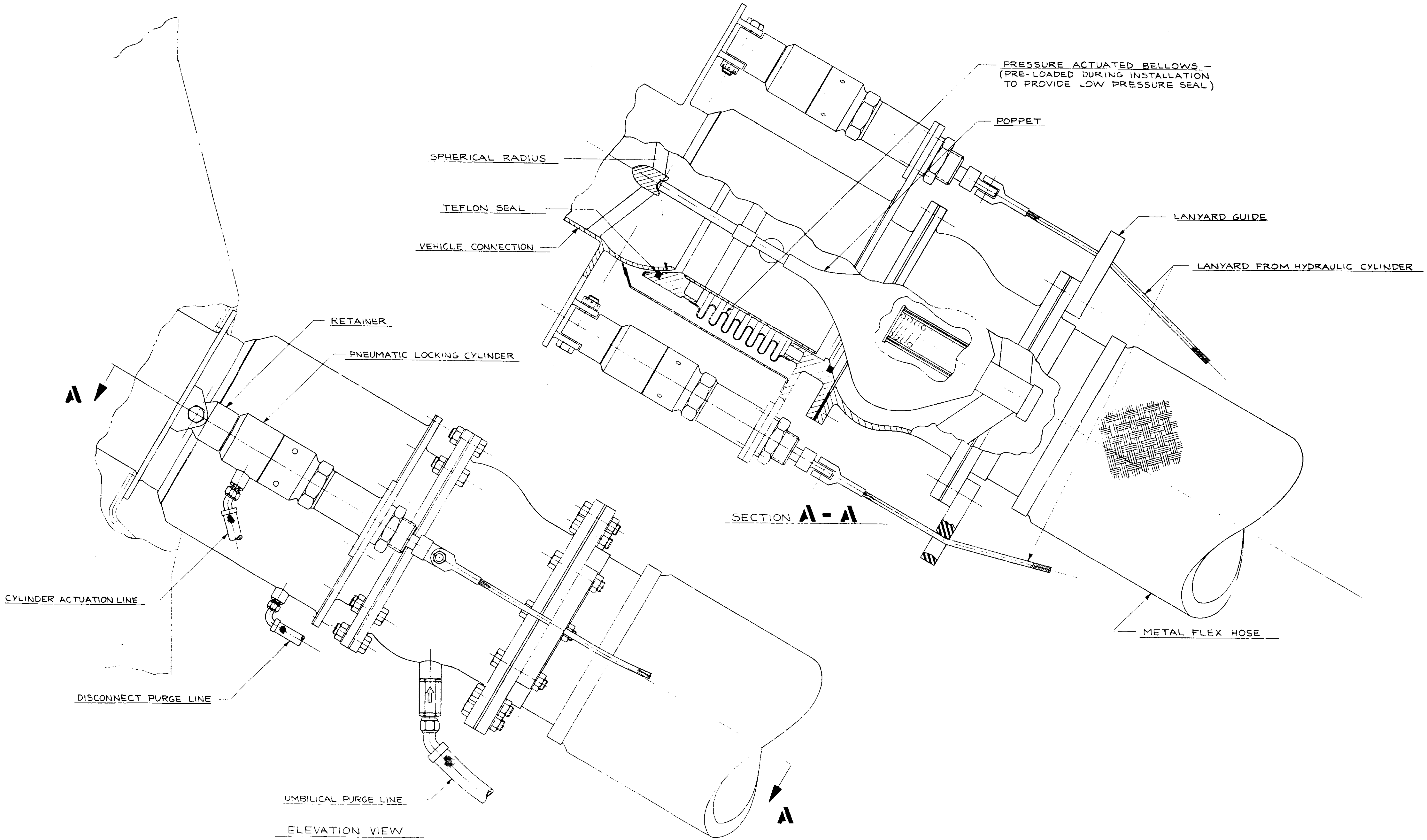


Figure 4-9. Hydrogen Vent Disconnect

SECTION V

SERVICE REQUIREMENTS

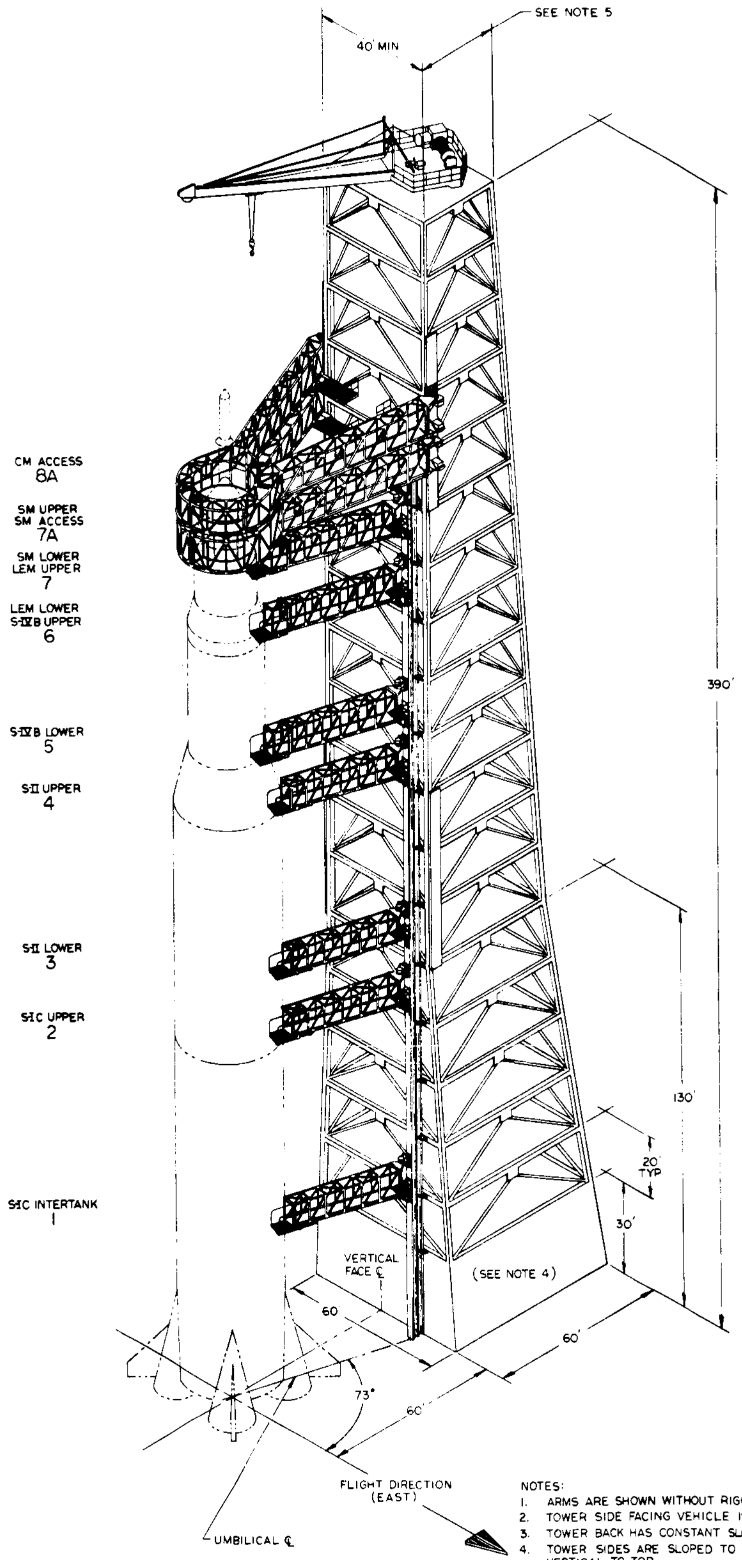
A. GENERAL REQUIREMENTS

The Saturn C-5 vehicles that will be launched from Complex 39 will be serviced from either the base of the vehicle or from an umbilical tower which uses an umbilical arm to span the gap between the tower and the vehicle to be launched (figure 5-1). The S-IC stage (first stage) will be the only stage serviced from the launcher deck. In addition, the S-IC stage will require two service arms to service the upper portion of the stage. Most stages require two service arms. These arms are referred to as the stage forward or aft service arms.

Servicing of the Saturn C-5 vehicle while on the launch pad will consist of:

(1) Supplying each stage with the necessary fuels, oxidizers, pressurization, hypergols, electrical connections, purging (when necessary).

(2) Providing access to areas that require inspection and/or service while on the launch pad. Each umbilical arm will require conveniently placed weather-proof, explosion proof outlets for electric and pneumatic tools, drop lights, etc., and communication stations to permit simultaneous connection of at least two telephone headsets.



NOTES:
1. ARMS ARE SHOWN WITHOUT RIGGING FOR STAGE SERVICES
2. TOWER SIDE FACING VEHICLE IS VERTICAL
3. TOWER BACK HAS CONSTANT SLOPE
4. TOWER SIDES ARE SLOPED TO 130 FT LEVEL THEN VERTICAL TO TOP
5. TOWER TOP DEPTH IS NOT CRITICAL IN THIS STUDY
6. THIS TOWER WILL ALSO HANDLE C-IB APOLLO CONFIGURATION
7. SPACE TO BE RESERVED ON TOWER CORNERS FOR POSITIONING ACCESS ARMS AT ANY LEVEL FROM 130' UPWARD

Figure 5-1. Proposed Umbilical Tower Configuration

Service arms, depending upon individual arm configurations, require the following:

(1) Means of supporting the propellant and pneumatic lines, ducts and cabling between tower and stage.

(2) Ground vehicle connectors.

(3) Means to automatically separate the connectors, ground half from stage half at lift-off, which shall be mechanically separable by vehicle motion in case of primary and secondary separation system failure.

(4) Means to remove the supporting structure, lines, cabling, and ground half stage connections from the vehicle drift envelop, which would preferably be mechanically retractable by vehicle motion in case of retraction system failure.

(5) Design flexibility to provide for automatic reconnect of propellant lines to the stage couplings to detank propellants in case of prerelease mission abort, should a practical solution of this problem be obtainable in time for this program.

(6) Electrical interruption of the umbilical circuits prior to disconnect.

(7) Means to accommodate all differential deflection between stage and tower.

B. TOWER REQUIREMENTS

In order to have instantaneous control, it will be necessary to provide the fluid controls as close as possible to the vehicle; therefore, it is necessary to provide an area on the tower decks near the base of the umbilical arms to install control consoles. At the present time the following requirements are necessary:

1. The S-IC Forward and Aft Arms.

Servicing areas on the tower decks will be required for a control console to control the action of the retraction mechanism.

2. The S-II and S-IVB Aft Arms.

These arms will each require space on a tower deck to install control consoles for the LH_2 and LOX valving complex, for temperature controls, for pneumatic consoles, and controls for the retraction mechanisms.

3. The S-II and S-IVB Forward Arms.

The S-II and S-IVB forward arms will each require approximately the same area on a tower deck as the aft arms.

C. S-IC STAGE SERVICE REQUIREMENTS

Service requirements for the S-IC stage are grouped into three areas: the base servicing area, the intertank access area, and the forward umbilical area. The S-IC base service requirements are of no concern in designing the service arms; however, they are part of the requirements of the vehicle, and therefore, are shown in figure 5-2 to

DESCRIPTION	No. Reqd.	Size	Media	Pressure	Temperature	Flow Rate
Launch Control, Prelaunch Digital Check-out, Fault Isolation	300		Electricity			
Ground Support Equipment Digital Check-out Test	100		Electricity			
First Motion, Safety and Abort; Malfunction	50		Electricity			
Heater Power	Unknown	16 Gage	Electricity			
Fuel Fill and Drain	1	6 inches (5.75 ID)	RP-1	54 psi	60°F to 100°F	2,000 gpm
LOX Fill and Drain	2	6 inches (5.75 ID)	LOX	90 psi	-279°F to 165°F	10,000 gpm Total
Fuel Tank Prepressurization (Quick Disconnect)	1	1-1/2 inches	Helium	300 psi	100°F	5 lb/sec
Helium Storage Bottle Connection (Quick Disconnect)	1	3/4 inch	Helium	3300 psi	100°F Fill -300°F Dump	0.5 lb/sec Fill 1.25 lb/sec Dump
LOX Tank Prepressurization Connection (Quick Disconnect)	1	2-1/2 inches	Helium	130 psi	70°F	10.5 lb/sec
LOX Bubbling Connection	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Fuel Bubbling Connection	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Hypergol Purge	1	1/4 inch	N_2	150 psi	Ambient	0.2 lb/sec per engine
LOX Dome Purge	1	3/4 inch	N_2	175 psi	Ambient	2.0 lb/sec per engine
Gas Generator Fuel Purge	1	1 inch	N_2	70 psi	Ambient	0.05 lb/sec per engine
Gas Generator LOX Purge	1	1/2 inch	N_2	55 psi	Ambient	0.01 lb/sec per engine
Fuel Injector Purge	1	3/4 inch	N_2	600 psi	Ambient	1.0 lb/sec per engine
Turbo Pump LOX Seal Purge	1	3/8 inch	N_2	60 psi	Ambient	0.02 lb/sec Per engine
Main Fuel Cavity Purge	1	3/8 inch	N_2	900 psi	Ambient	Unknown
Hydraulic Supply	1	1-1/2 inches	Hyd Fluid	1500 psi	Approx Ambient	Unknown
Hydraulic Return Check-out	1	1-1/4 inches	Hyd Fluid	25 psi	Approx Ambient	Unknown
Thrust Chamber Water Fill	1	1/2 inch	H_2O	70 psi	50°F	Unknown
LOX Tank Pressurization	1	3 inches	GOX	1500 psi	Ambient	8.1 lb/sec
Fuel Tank Pressurization	1	2 inches	Helium	120 psi	100°F	0/60 lb/sec
Heat Exchanger Supply	1	2 inches	Helium	200 psi	90°F	0.60 lb/sec

Figure 5-2. S-IC Service Requirements

complete the requirements of the Saturn C-5 configuration.

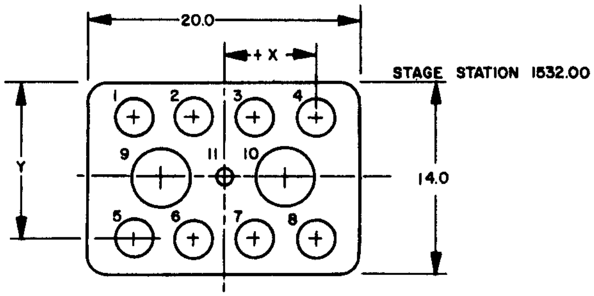
The S-IC intertank service arm disconnect requirements are unsettled. It is used to provide personnel access to the intertank area to do minor servicing in this area. If possible, this arm should be retracted as soon as the signal is given for personnel to clear the area.

The forward service arm required for the S-IC stage will require the disconnects and characteristics shown in figure 5-3. The forward service arm will also provide personnel access to the forward umbilical area to service this area. Umbilical connections are required in this area until 1.5 to 0.5 seconds before lift-off.

D. S-II STAGE SERVICE REQUIREMENTS

Servicing of the S-II stage (figure 4-3) at the launch pad, will be accomplished through four general areas: the aft umbilical area, the forward umbilical area, the aft access door to the engine compartment, and the forward access door into the instrumentation area. Figure 4-3 lists the disconnects and requirements for each service.

The aft umbilical area (figure 5-4) of the S-II stage will require two individual fluid supply lines and one or more multidisconnect plates. The individual supply lines to the vehicle will supply the LH_2 and LOX propellants. The flow rates for these liquids are such that they require eight-inch lines for the most efficient conditions. Each line will require a valving complex capable of the following through its disconnect at the vehicle: a full flow rate as indicated in the table in figure 4-3;



UMBILICAL CONNECTION
LOOKING INBOARD

NOTES:

1. Estimated Maximum Weight
   Vehicle half of connection (complete) - approximately 70 lb
   Ground half of connection (complete) - approximately 180 lb

2. Maximum number of personnel required on arm at one time = 2 (plus 300 lb of tools)

3. Services required on arm but not through umbilical connector:
   110-Volt 60-cycle, 30-amp, grounded
   220-Volt 60-cycle, 30-amp, grounded neutral
   Station air outlet (psi)

No.	Function	Medium and Pressure	Nom Size (Connector)	Location		Flow Rate	Temper-ature	Line Characteristics			
				X	Y			Type	Material	Size	Wt/Ft.
1	Electrical		Shell 40	-6.75	2.5			Cable - 60 Wire	Copper Wire	2 In. Max OD	2.5 Max 2.0 Avg
2	Electrical		Shell 40	-2.25	2.5			Cable - 60 Wire	Class H Insul	2 In. Max OD	2.5 Max 2.0 Avg
3	Electrical		Shell 40	+2.25	2.5			Cable - 60 Wire	Class H Insul	2 In. Max OD	2.5 Max 2.0 Avg
4	Electrical		Shell 40	+6.75	2.5			Cable - 60 Wire	Class H Insul	2 In. Max OD	2.5 Max 2.0 Avg
5	Electrical		Shell 40	-6.75	11.5			Cable - 60 Wire	Class H Insul	2 In. Max OD	2.5 Max 2.0 Avg
6	Electrical		Shell 40	-2.25	11.5			Cable - 60 Wire	Class H Insul	2 In. Max OD	2.5 Max 2.0 Avg
7	Electrical		Shell 40	+2.25	11.5			Cable - 60 Wire	Class H Insul	2 In. Max OD	2.5 Max 2.0 Avg
8	Electrical		Shell 40	+6.75	11.5			Cable - 60 Wire	Copper Wire	2 In. Max OD	2.5 Max 2.0 Avg
9	Cooling In		4 Inches	-4.50	7.0			Fabric Duct	Class H Insul	4 Inches	0.8 Lb.
10	Cooling Out		4 Inches	+4.50	7.0			Fabric Duct	Class H Insul	4 Inches	0.8 Lb.
11	Disconnect	Air		0.0	7.0		Ambient	Tube	Stainless Stl.		Neg

Figure 5-3. S-IC Forward Umbilical Services

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NOTE:
1. FOR FIND NUMBER FUNCTIONS, SEE FIGURE 4-3.

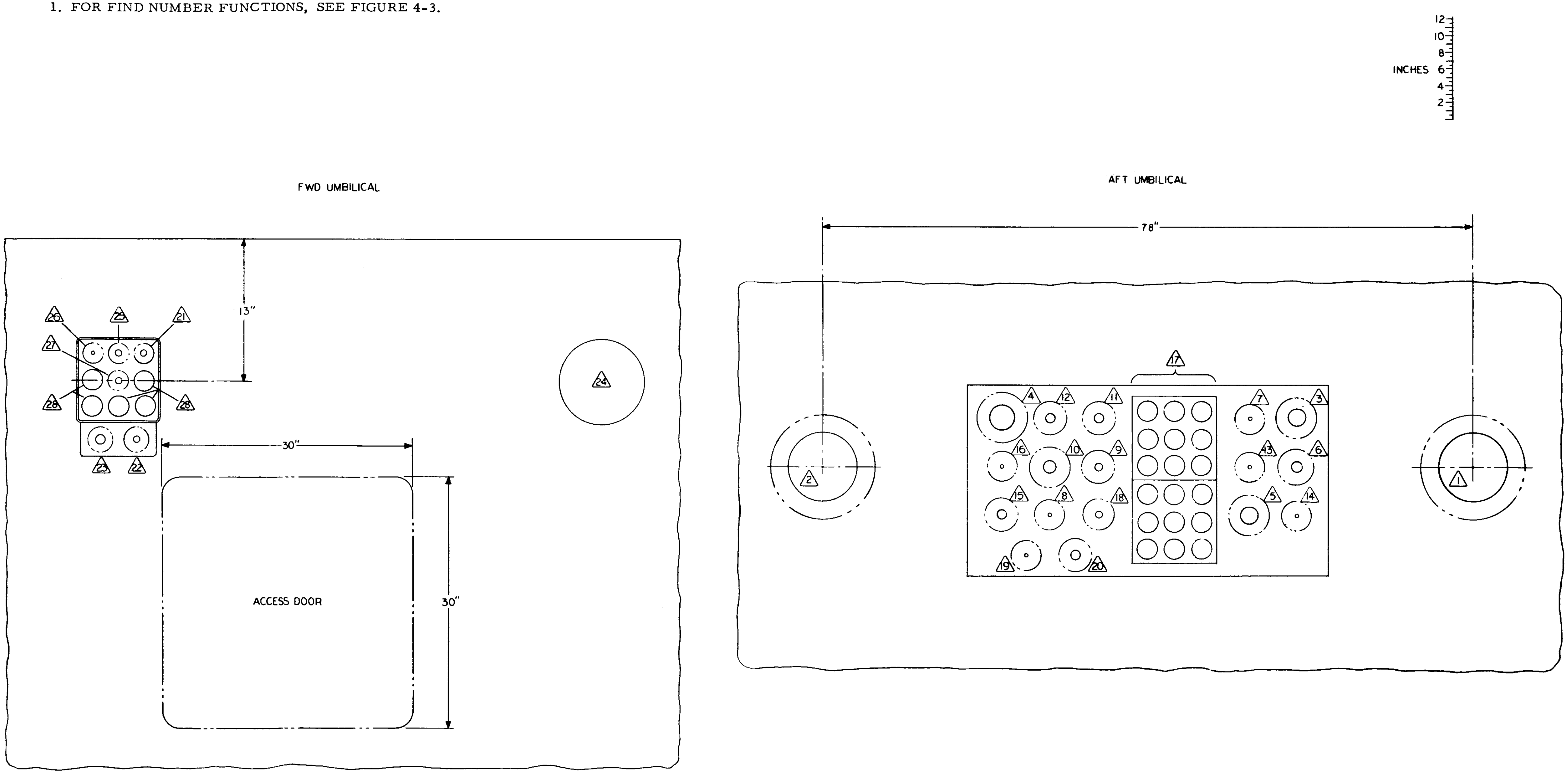

Figure 5-4. S-II Umbilical Areas

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a variable flow rate for topping; detanking after an abort; purging fluid lines before and after fueling the vehicle. Disconnects of this size will require powered equipment for handling. In designing mechanical support for the disconnects, allowances must be made for the sway or misalignment between the vehicle and the tower. Possible misalignment at the aft umbilical arm can be determined from curves in Section VI. To minimize loads imposed on the vehicle by the ground half of the disconnects, the flexible portion of the supply lines should be as close as feasibly possible to the actual disconnect. This requirement holds true not only for individual propellant disconnects, but for the multidisconnect plate (figure 5-5), as well. The two large disconnects will transmit cryogenic liquids. Insulation will be required, also special clean conditions will be required before transmitting LH_2 and LOX propellants. The multidisconnect plates will carry all of the electrical and fluid disconnects for the aft portion of the S-II stage. As indicated in the table on figure 4-3, the LOX tank fill valve actuator must be connected until lift-off; therefore, the aft arm cannot be retracted until after this time. Prelaunch disconnect and remote reconnect will require that this function be transferred to the upper umbilical.

The forward umbilical area (shown in figure 5-4 with requirements as outlined in the table on figure 4-3) will require a gaseous hydrogen vent disconnect and a multidisconnect area. The hydrogen vent line will be about 10 inches in diameter and the disconnect should be the

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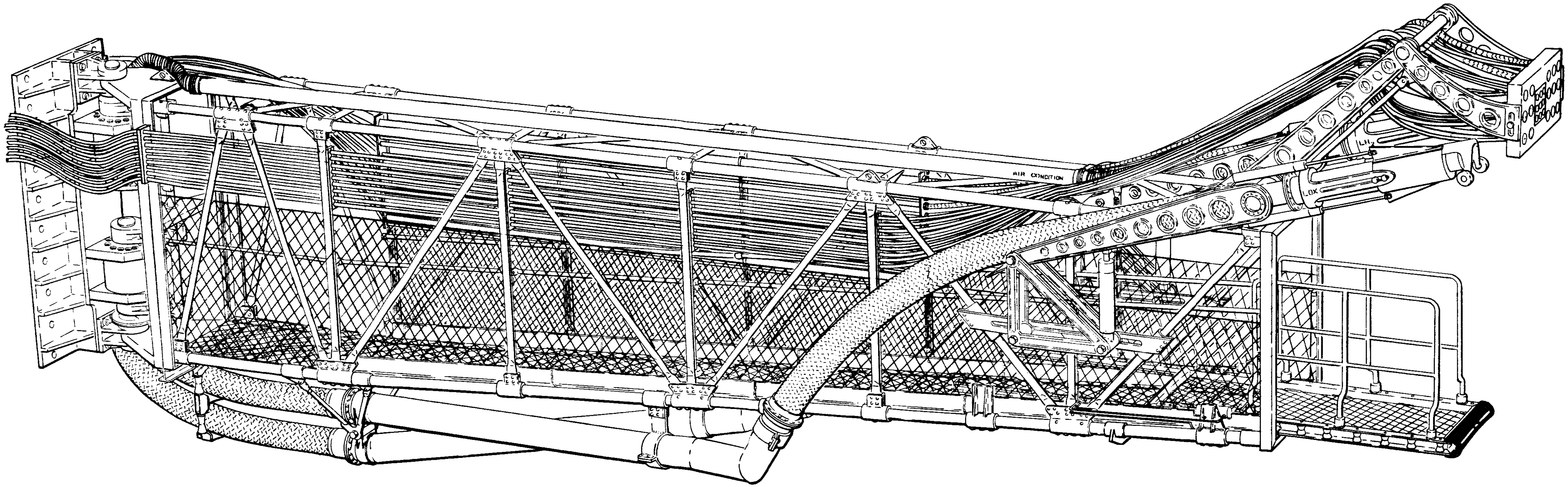

Figure 5-5. A Service Arm Concept

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type that can be manually installed, and disconnected both by a signal and a lanyard pull during lift-off of the vehicle. The multidisconnect plate carrying the electrical and fluid disconnects to the upper portion of the vehicle should be disconnected in the same manner as the hydrogen vent line. After this operation, the S-II forward umbilical arm should be retracted. Possible misalignment at the forward umbilical arm can be determined from curves in Section VI.

The lower access door leading into the S-II stage engine compartments will be located approximately 12 feet below the aft umbilical service area (figure 4-3). Access to the aft umbilical disconnect area and the aft access door will require either two service arms from the tower or a secondary platform leading from the aft service arm to the umbilical disconnect area or the access door area.

The forward access door is located near the umbilical disconnect area and therefore will not require an additional arm or secondary platform from the existing forward service arm.

E. S-IVB STAGE SERVICE REQUIREMENTS

The servicing of the S-IVB stage (figure 4-4), while on the launch pad, will be accomplished through two service arms; the aft service arm, and the forward service arm as shown in figures 4-8 and 4-9.

1. Aft Umbilical Services.

The function of the aft umbilical is to provide electrical, propellant, gas, and air conditioning services from the umbilical

tower to the stage skin interface as shown in figure 4-8. Possible misalignment for the aft service arm can be determined from curves in Section VI. Umbilicals at this level include cabling, ground and flight side connectors, fluid and gas lines, air-conditioning ducts, and their connectors as listed in figure 5-6. Symbol marked items are the hypergolic fuel and oxidizer services, which are to be moved to the forward umbilical if prelaunch release is desired for the aft umbilical, for the S-IVB attitude control and positive ullage systems. These lines carry an oxidizer, nitrogen tetroxide (N_2O_4); and a fuel, monomethyl hydrazine ($CH_3N_2H_3$). Both chemicals are extremely toxic. Nitrogen tetroxide is a corrosive oxidizing agent, insensitive to heat, shock, and detonation. It is nonflamable with air but capable of supporting combustion. It is capable of inflicting severe chemical burns and has a maximum allowable inhalation of 2.5 ppm/day. Monomethyl hydrazine is sensitive to catalytic oxidation. It is capable of spontaneous ignition when exposed to air on large surfaces, e.g., rags. It is a severe respiratory irritant with maximum allowable inhalation of 0.5 ppm/day.

Hypergolic characteristics must be thoroughly understood by all affected design and service personnel and to this purpose a Douglas Aircraft Company report on hypergolics is included in Appendix A.

At the stage skin interface, a collector plate carries all ground side umbilical connectors; electrical, fluid, gas, and air-conditioning,

AFT UMBILICAL

FIND NO.	FUNCTION	QUAN	MEDIA	OPER PRESS.	FLOW RATE	TEMP °F	CONNECTOR WT	CONNECTOR SIZE	LINE TYPE WT	LINE TYPE SIZE	REQ'D FOR SAFING
1	LOX	1	LOX	100	1000 GPM	-290	6#	4"	12#/FT	4" I.D.	YES
2	LH_2	1	LH_2	50	3000 GPM	-420	6#	4"	12#/FT	4" I.D.	YES
3	FUEL PREPRESS	1	HE	300		-300	1.5#	3/4"	.8#/FT	3/4"	YES
4	COLD HE BOTTLES	1	HE	3000	28# MIN	-400	1#	1/2"	.5#/FT	1/2"	YES
5	VALVE ACTUAT	1	HE	425		AMB	.5#	1/4"	.2#/FT	1/4"	YES
6	LOX PUMP SEAL PURGE	1	HE	50		AMB	.5#	3/8"	.2#/FT	3/8"	NO
7	LH_2 PUMP SEAL PURGE	2	HE	50		AMB	.5#	3/8"	.2#/FT	3/8"	NO
8	TURBINE START BOTTLE VENT ACTUAT	1	HE	425		AMB	.5#	1/4"	.2#/FT	1/4"	YES
9	TURBINE START BOTTLE H_2 SUPPLY	1	GH_2	800		-200	.5#	5/8"	.2#/FT	5/8"	NO
10	VALVE ACTUAT BOTTLE COLD HE SUPPLY	1	HE	2700		-200	.5#	1 4"	.2#/FT	1/4"	NO
11	ELECT.	5	—	—	—	—	3# EA	SH40	2#/FT	60 C	NO
12	AIR CONDITIONING	2	AIR & GN_2	1/2 PSI			2# EA	8"	1#/FT	8" (10" OD)	YES
31	COLD H_2 SUPPLY	1	GH_2	800	28# MIN	-200	1#	1/2"	.5#/FT	1/4"	NO
32	ENG GAS GEN COOLDOWN LO_2	1	LO_2			-297		2"		2"	NO
33	ENG GAS GEN COOLDOWN LH_2	1	LH_2			-423		2"		2"	NO
34	ENG GAS GEN COOLDOWN LH_2 VENT	1	GH_2			-423		1"		1"	NO
35	TURBINE SEAL BLEED	1	GH_2 + HE			-423		1/4"		1/4"	NO
36	TURBINE START BOTTLE RELIEF	1	GH_2			-200		5/8"		5/8"	YES
37	TURBINE START BOTTLE VENT	1	GH_2			-200		5/8"		5/8"	YES
38	COLD HE BOTTLE VENT	1	GH_2	-800		-200		1/2"		1/2"	YES

FWD UMBILICAL

	FIND NO.	FUNCTION	QUAN	MEDIA	OPER PRESS	FLOW RATE	TEMP °F	CONNECTOR WT	CONNECTOR SIZE	LINE TYPE WT	LINE TYPE SIZE	REQ'D FOR SAFING
	21	GH_2 VENT	1	GH_2	16 PSI		-423	4.5#	6"	10#/FT	8" (10 OD)	YES
	22	(NOT USED)										UNDECIDED
	23	ELECT.	9	—	—	—	—	3# EA	SH40	2#/FT	60 C	
⟨3⟩	13	(HYP FUEL) TRANSFER LINE PURGE	1	HOT GN_2	50 PSI			.5#	1/4"	.2#/FT	1/4"	
⟨3⟩	14	(HYP OXID) TRANSFER LINE PURGE	1	HOT GN_2	50 PSI			.5#	1/4"	.2#/FT	1/4"	
⟨3⟩	15	(HYP FUEL) FILL	1	HYP FUEL		10 GPM	AMB	.7#	3/8"	.4#/FT	3/4"	
⟨3⟩	16	(HYP FUEL) RETURN	1	HYP FUEL		10 GPM	AMB	.7#	3/8"	.4#/FT	3/4"	
⟨3⟩	17	HE PRESS. FILL	1	HE	3000		AMB	.5#	1/4"	.2#/FT	1/4"	
⟨3⟩	18	(HYP OXID) RETURN	1	N_2O_4		10 GPM	20-60	.7#	3/8"	.4#/FT	3/8"	
⟨3⟩	19	(HYP OXID) FILL	1	N_2O_4		10 GPM	20-60	.7#	3/8"	.4#/FT	3/8"	
⟨3⟩	20	(HYP OXID) TANK VENT	1	HE (N_2O_4)			20-60	.5#	1/4"	.2#/FT	1/4"	
⟨3⟩	30	(HYP FUEL) TANK VENT	1	HE (HYP FUEL)			AMB	.5#	1/4"	.2#/FT	1/4"	

AFT UMBILICAL ARM LOADS

LINES 38.5#/FT X 48 FT	1850 #
PROPELLANT IN LINES LOX 283, LH_2 17	300 #
10% BRACKET FACTOR	215 #
TOTAL MAX UNIFORM LINE & BRACKET LOADS C G IS 26' FROM ARM HINGE LINE	2365 #
DISCONNECTS 26.8# & CENTER PLATE 40#	66.8#
LOX & LH_2 DISCONNECT & RECONNECT MECH	800 #
CENTER PLATE RETRACTION MECH	200 #
3 MEN ON PLATFORM	600 #
TOTAL CONCENTRATED LOAD C G IS 41' FROM ARM HINGE LINE	1666.8#
GROSS ARM LOADING C G IS 32.7' FROM ARM HINGE LINE	4000 #

ARM STRUCTURE EST WT 3000#

FWD UMBILICAL ARM LOADS

LINES 26# FT X 48 FT	1240 #
10% BRACKET FACTOR	124 #
TOTAL MAX UNIFORM LINE & BRACKET LOADS C G IS 26' FROM ARM HINGE LINE	1364 #
DISCONNECTS 30# & PLATE 30#	60 #
PLATE RETRACTION MECH	200 #
3 MEN ON PLATFORM	600 #
TOTAL CONCENTRATED LOAD C G IS 41' FROM ARM HINGE LINE	860 #
GROSS ARM LOADING C G IS 31.6' FROM ARM HINGE LINE	2224 #

NOTES:
1. FOR DETAIL OF UMBILICAL AREAS SEE FIGURE 5-7.
2. UMBILICAL AND ACCESS ℄ 73° FROM POS I TOWARD POS II.
3. SYMBOL ⟨3⟩ SERVICES WILL BE REMOVED FROM AFT PLATE & INCORPORATED INTO FWD PLATE IF AFT PLATE IS NOT TO BE A FLY-AWAY CONNECTION.
4. SEE APPENDIX A FOR COMPARATIVE SAFING REQUIREMENTS S-IVB.

Figure 5-6. S-IVB Service Requirements

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except for the main propellant lines, LH_2 and LOX, which are separately connected through retractable fill nozzles located outboard of the collector plate. The ground side collector or carrier plate and connector cluster configuration is shown in figure 5-7. LOX and LH_2 transfer nozzles and stage couplings are shown in figures 4-8 and 4-9.

a. The Liquid Oxygen Transfer Line

The liquid oxygen transfer line connecting the umbilical tower piping to the vehicle connection will be mounted on the aft service arm and will be used for filling, topping, and draining the vehicle liquid oxygen tank. The line will also be used for the blanket purge of the tank. Requirements are tabulated on figure 5-6. Vacuum jacketed, convoluted metal flex hoses should be used to provide flexibility for separating the disconnect from the vehicle and retracting the service arm out of the drift envelop. The hose adjacent to the vehicle disconnect shall be long enough to allow for the maximum relative motion between the vehicle and the service arm. The service arm pivot hose will be mounted beneath the pivot axis. Both ends of the pivot hose will be at the same elevation to eliminate torsion in the hose. The hose will be supported in the middle to help keep the hose in a horizontal plane during propellant flow and service arm retraction. The two hose assemblies will be connected by a length of vacuum-jacketed pipe mounted to the side of the service arm. The outer pipe wall will contain one or more bellows to allow for the temperature difference

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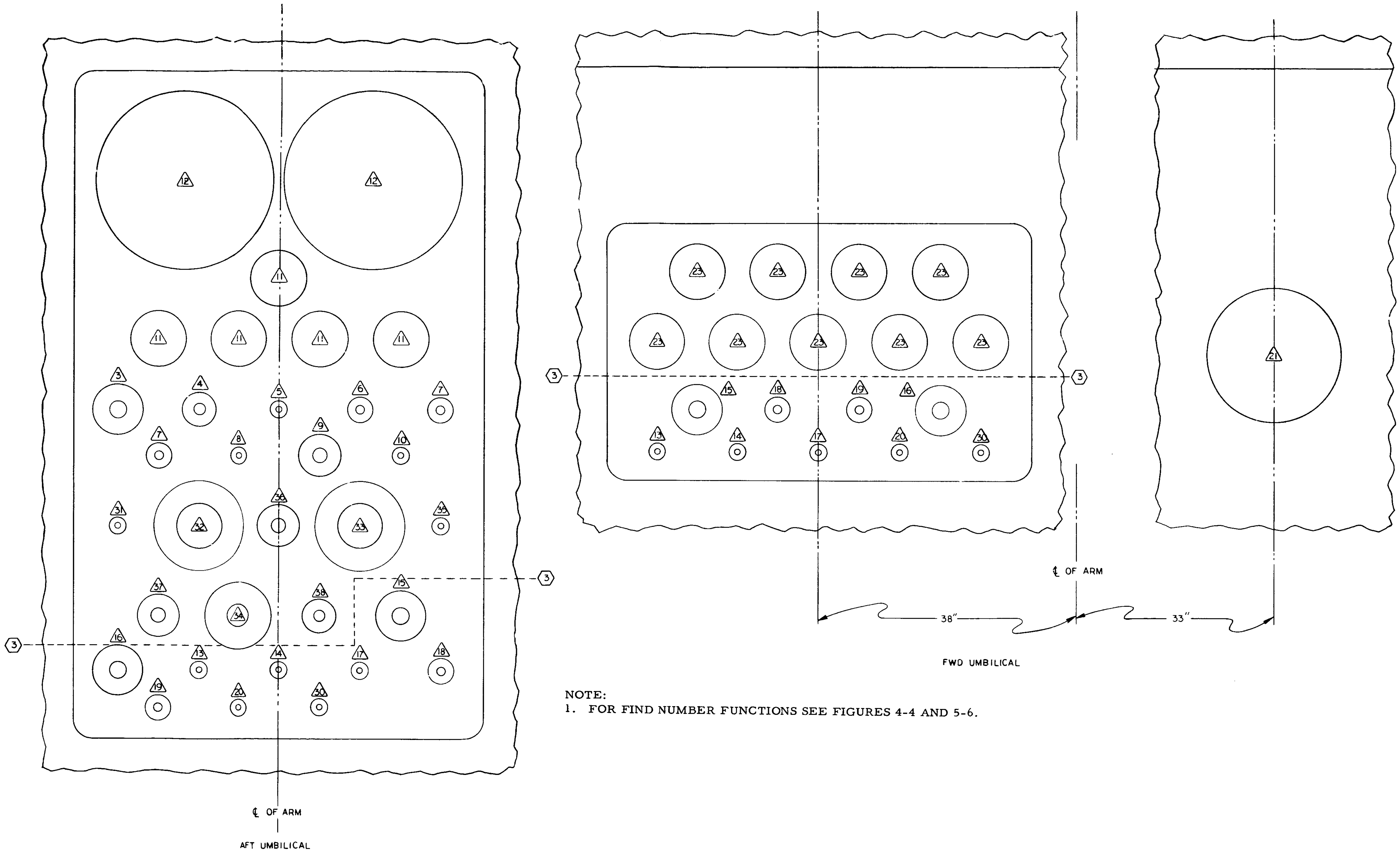

NOTE:
1. FOR FIND NUMBER FUNCTIONS SEE FIGURES 4-4 AND 5-6.

Figure 5-7. S-IVB Umbilical Areas

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between the inner and outer pipe. The pipe mounting brackets shall be designed to permit bowing and thermal contraction of the line. The connections between the hose and the service arm and the umbilical tower piping will be of the bayonet type. The connection joining the hose to the ground half of the quick disconnect coupling will not be vacuum jacketed.

Each hose assembly and the service arm pipe assembly will contain a vacuum valve with a suitable fitting for connecting to a vacuum pump hose. Each assembly will also contain a vacuum gage and a relief valve or burst diaphragm connected to the annular vacuum space. Prior to disconnect, the umbilical transfer line will be drained and purged with ambient temperature gaseous nitrogen. To accomplish this, a one-half inch purge line will be routed out the service arm and connected through a check valve to the ground half of the liquid oxygen disconnect coupling. A one-quarter inch gaseous nitrogen purge line will be routed out the service arm to a purge boot around the disconnect coupling and the nonvacuumed end of the umbilical hose. A continuous flow of dry gaseous nitrogen at less than one psig will be used to prevent ice formation around the disconnect fitting and decrease the concentration of oxygen in case of leakage at the disconnect seal. The purge lines will use metal convoluted hoses where flexibility is required, and stainless steel tubing elsewhere on the service arm.

b. Liquid Hydrogen Transfer Line

The liquid hydrogen transfer line connecting the umbilical tower piping to the vehicle connection will be mounted on the aft service arm and shall be used for filling, topping, and draining the vehicle liquid hydrogen tank. The line will also be used for the blanket purge of the tank. Requirements are tabulated on figure 5-6.

The hardware requirements for the line are similar to those noted for the liquid oxygen transfer line. Where possible, identical components should be used for both propellant transfer lines. The liquid hydrogen pivot hose will be mounted directly beneath the liquid oxygenhose and both hoses will be supported by the same brackets.

The purge line hardware will be similar to that used for the liquid oxygen system except that gaseous helium will be used to purge and drain the liquid hydrogen transfer line and provide an external purge around the noninsulated disconnect. The disconnect purge will prevent ice and liquid air forming on the connection and provide a less combustible atmosphere when mixed with expected leakage past the disconnect seal.

c. Pneumatic and Hypergolic Propellant Lines

The pneumatic and hypergolic lines connecting the umbilical tower lines to the vehicle connections will be mounted on the aft service arm. Requirements are tabulated on figure 5-6.

Metal or "Teflon" hoses will be used to provide flexibility for separating the umbilical disconnect from the vehicle and retracting the service arm out of the drift envelop. The hoses adjacent to the vehicle connections shall be long enough to allow for the maximum relative motion between the vehicle and the service arm. The service arm pivot hoses will be mounted above the pivot axis. Both the service arm ends and tower ends of the hoses will be at the same elevation to prevent torsion in the hoses during service arm retraction. The hose assemblies will be connected by stainless steel tubing mounted on the service arm. Cold helium and hydrogen lines will be insulated. The cold lines will be routed and attached to the arm in such a manner so as to allow for thermal contraction.

2. Aft Access Service.

The aft service arm is used to provide entry into the S-IVB aft cavity for checkout and repair.

To permit removal of the aft cavity equipment from the vehicle, a door is installed in the flared aft interstage as indicated in figure 4-4. The service arm shall be suitably designed to permit straight-up walk-through from the tower to the aft interstage door by service personnel carrying a 30 x 30 x 30-inch package weighing a maximum of 50-pounds, and its motion shall be suitably controlled or the arm so positioned and locked that package transfer through the

vehicle door shall not be impaired.

Arm structure and umbilical arrangement shall be such that all connectors, cables, lines, and ducts are accessible for hookup, service, and repair with the arm extended.

3. S-IVB Forward and Instrument Unit Umbilical Service.

The function of the forward umbilical is to provide electrical, air-conditioning, and hydrogen vent services from the umbilical tower to the S-IVB stage forward cavity and the instrument unit above it. Possible misalignment for the forward service arm can be determined from curves in Section VI.

The forward umbilicals include S-IVB and instrument unit cabling, air-conditioning ducts, hydrogen vent line, and space provision for possible addition of hypergolic lines, and their ground-vehicle connectors as listed in figure 5-6. The symbol marked items are hypergolic services. All electrical service connectors for S-IVB and the instrumentation unit above it are collected in interconnected carrier plates located to the left of the instrument unit access door. The location and cluster configuration is shown in figure 5-7.

a. Gaseous Hydrogen Vent Line

The hydrogen vent line enters the vehicle through a separate umbilical carrier plate located to the right of the access door.

The gaseous hydrogen vent line connecting the umbilical tower vent line to the vehicle connection shall be mounted on the forward

service arm, and shall be used to transfer gaseous hydrogen vented from the vehicle fuel tank to the vent stack. Requirements are tabulated on figure 5-6.

Convoluted metal flex hoses will be used to provide flexibility for separating the disconnect from the vehicle and retracting the service arm out of the drift envelop. The hose adjacent to the disconnect shall be long enough to allow for the maximum relative motion between the vehicle and the service arm. The service arm pivot hose will be mounted beneath the pivot axis. Both ends of the pivot hose will be at the same elevation and the hose will be supported in the middle. This will keep the hose in a horizontal plane during service arm retraction in order to prevent torsion in the hose.

The two hose assemblies will be connected by a stainless steel tube mounted to the service arm. The tube shall be attached to the arm in such a manner so as to allow for thermal contraction of the line. The tube and hose assemblies will be insulated.

The vent line will be purged with gaseous helium prior to disconnect. The vent disconnect will have an external helium purge similar to the liquid hydrogen fill connection purge. The purge line hardware will be similar to that used for the liquid hydrogen transfer line.

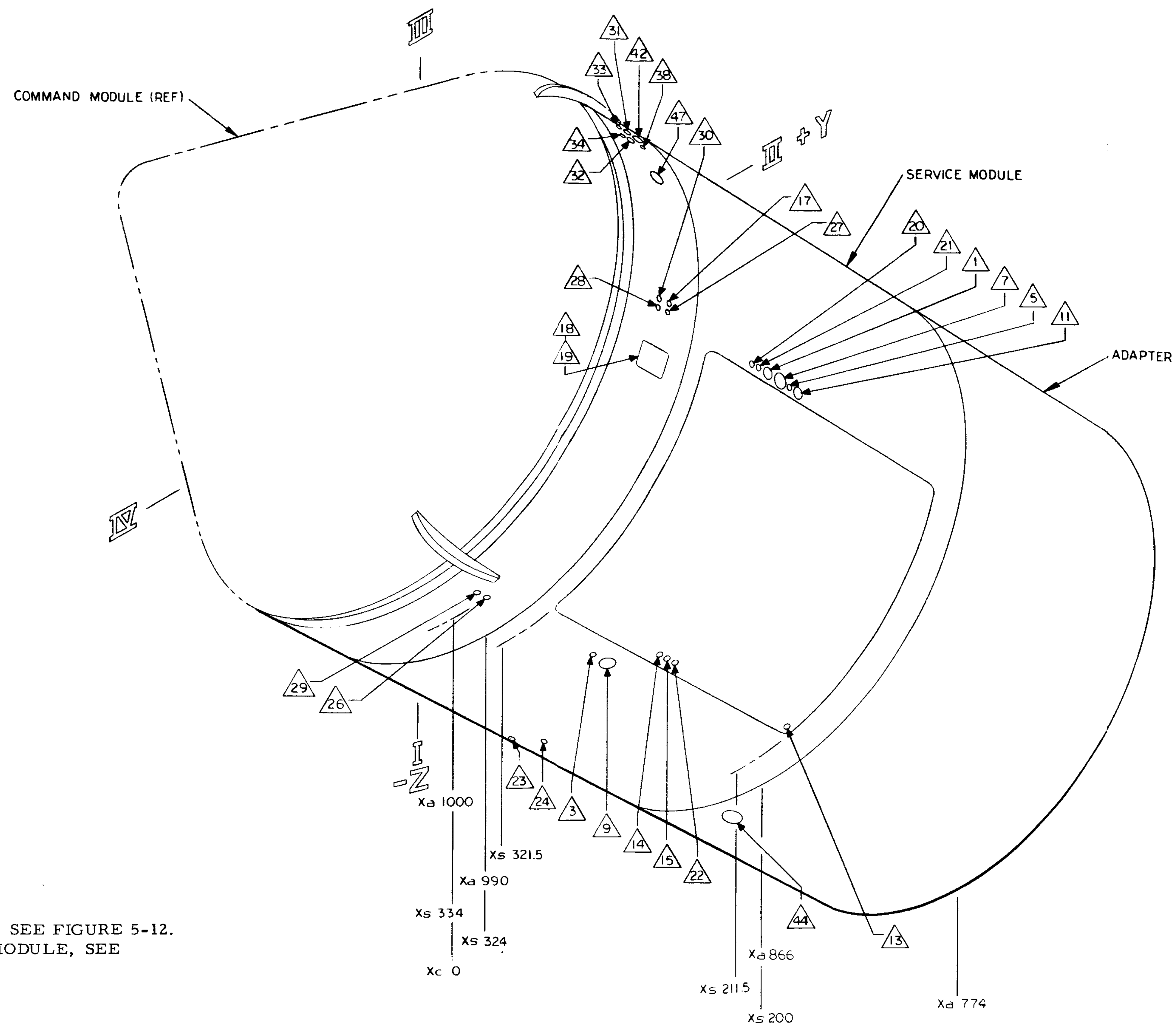
b. S-IVB and Instrument Unit Access Service.

Access to the S-IVB forward cavity and instrument unit will be through the access door located in the guidance or instrumentation unit above the S-IVB stage, as indicated in figure 4-4. Line sizes, configuration, and umbilical characteristics are listed in figure 5-6.

F. APOLLO SERVICE MODULE AND COMMAND MODULE

The Apollo spacecraft will require servicing for the Service Module and the Command Module. To service the spacecraft in its present concept, 360-degree access is required for both modules. Figures 5-8, 5-9, and 5-10 illustrate the fluid servicing areas for the Service Module and figure 5-11 illustrates the specific fluid servicing areas for the Command Module. Fluid servicing disconnects and their respective functions are tabulated in figure 5-12 for the Service Module and Command Module.

The tanks for the main service propulsion engine, located in the Service Module, and the reaction control motors located in the Service Module and Command Module will be filled with hypergolic propellants. The fuel is a mixture of unsymetrical dimethyl hydrogen and hydrazine. The oxidizer is nitrogen tetroxide. Gaseous purging and drying of the service propulsion tanks and systems, also the reaction control systems will be accomplished through the fill disconnects. At the present time, flushing of these systems is being considered; however, this has not been established as a definite requirement. Helium gas will be used for



NOTES:
1. FOR FIND NUMBER FUNCTIONS, SEE FIGURE 5-12.
2. FOR OTHER SIDE OF SERVICE MODULE, SEE FIGURE 5-9.

Figure 5-8. Service Module Umbilical Areas (View A)

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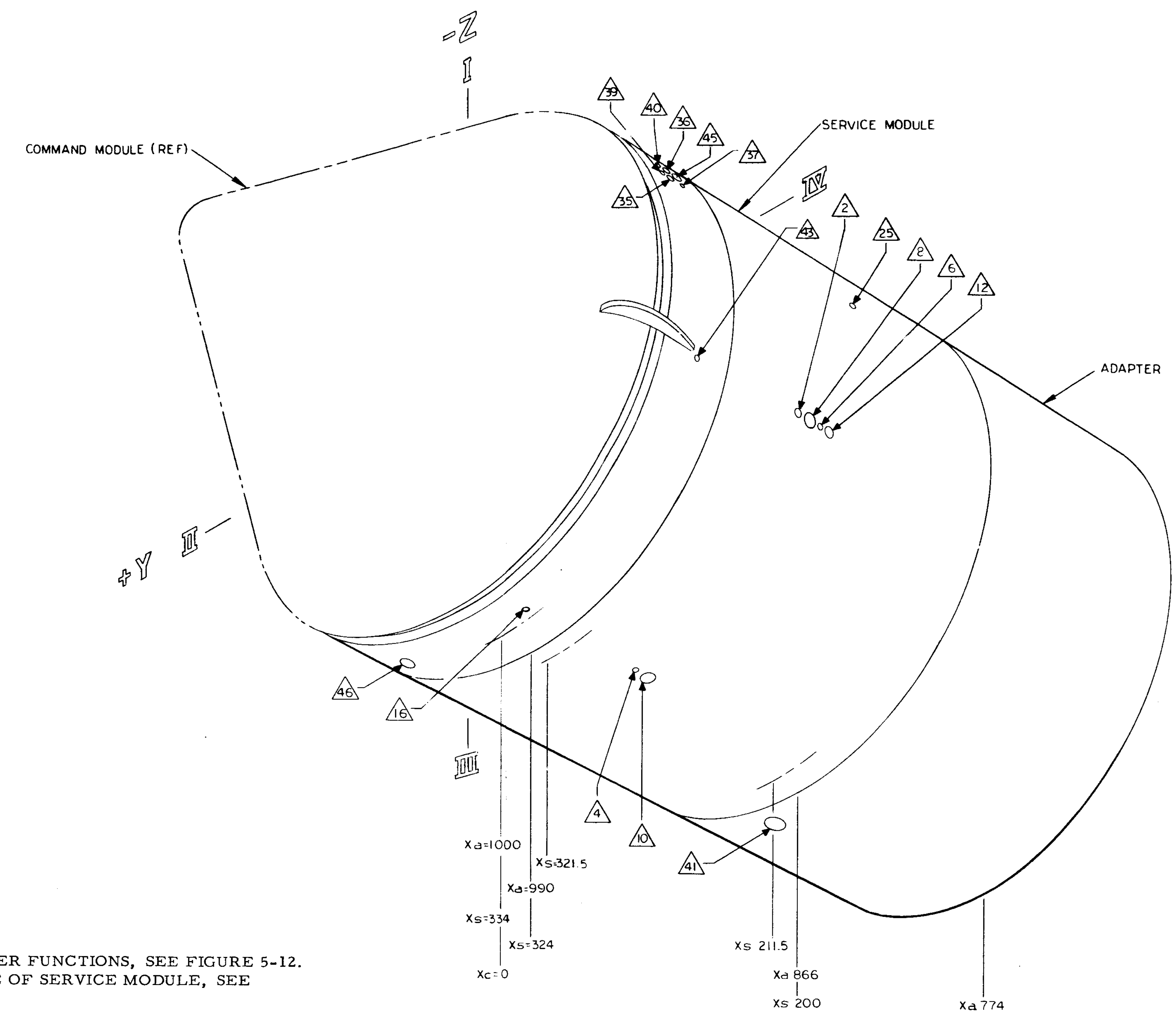

NOTES:

1. FOR FIND NUMBER FUNCTIONS, SEE FIGURE 5-12.
2. FOR OTHER SIDE OF SERVICE MODULE, SEE FIGURE 5-8.

Figure 5-9. Service Module Umbilical Areas (View B)

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TABLE 5

EXTERNAL SURFACE SERVICING CONNECTIONS OF APOLLO

SERVICE MODULE

FIND NO.	SERVICE CONNECTION (PURPOSE)	LINE SIZE & FITTING	DISCONNECT	T - TIME OF DISCONNECT	CENTERLINE LOCATION STATION	Y	Z	GROUP	MISCELLANEOUS
1	OXYGEN FILL LINE FOR TANK "A"	3/8"DIA	MANUAL	T - 6 HR	Xs=287.3	73.8	-20.0	E.C.S.	
2	OXYGEN FILL LINE FOR TANK "B"	3/8"DIA	MANUAL	T - 6 HR	Xs=287.3	-73.8	20.0	E.C.S.	
3	HYDROGEN FILL LINE FOR TANK "A"	3/8"DIA	MANUAL	T - 6 HR	Xs=278.3	13.0	-75.2	E.C.S.	
4	HYDROGEN FILL LINE FOR TANK "B"	3/8"DIA	MANUAL	T - 6 HR	Xs=287.3	-13.0	75.2	E.C.S.	
5	NITROGEN FILL LINE FOR TANK "A"	1/4"DIA	MANUAL	T - 6 HR	Xs=279.8	73.8	-20.0	E.C.S.	
6	NITROGEN FILL LINE FOR TANK "B"	1/4"DIA	MANUAL	T - 6 HR	Xs=279.8	-73.8	20.0	E.C.S.	
7	OXYGEN FILL VENT LINE FOR TANK "A"	3/4"DIA	MANUAL	T - 6 HR	Xs=283.3	73.8	-20.0	E.C.S.	
8	OXYGEN FILL VENT LINE FOR TANK "B"	3/4"DIA	MANUAL	T - 6 HR	Xs=283.3	-73.8	20.0	E.C.S.	
9	HYDROGEN FILL VENT LINE FOR TANK "A"	3/4"DIA	MANUAL	T - 6 HR	Xs=283.3	13.0	-75.2	E.C.S.	
10	HYDROGEN FILL VENT LINE FOR TANK "B"	3/4"DIA	MANUAL	T - 6 HR	Xs=283.3	-13.0	75.2	E.C.S.	
11	NITROGEN FILL VENT LINE FOR TANK "A"	1/2"DIA	MANUAL	T - 6 HR	Xs=276.8	73.8	-20.0	E.C.S.	
12	NITROGEN FILL VENT LINE FOR TANK "B"	1/2"DIA	MANUAL	T - 6 HR	Xs=276.8	-73.8	20.0	E.C.S.	
13	WATER FILL LINE	1/4"DIA	MANUAL	T - 6 HR	Xs=216.5	20.5	-73.5	E.C.S.	
14	GLYCOL FILL LINE	1/4"DIA	MANUAL	T - 6 HR	Xs=273.5	20.5	-73.5	E.C.S.	
15	GLYCOL FILL VENT LINE	1/4"DIA	MANUAL	T - 6 HR	Xs=271.0	20.5	-73.5	E.C.S.	
16	HYDROGEN OVERBOARD PRESSURE RELIEF	1/4"DIA	AUTOMATIC	T - 5 SEC	Xs=334.0	-13.0	75.2	E.C.S.	
17	NITROGEN OVERBOARD PRESSURE RELIEF	1/4"DIA	AUTOMATIC	T - 5 SEC	Xs=332.75	73.8	-20.0	E.C.S.	
18	ELECTRICAL GROUND CHECK OUT	2 PLUGS 3"DIA	AUTOMATIC	T - 5 SEC	Xs=334.0	71.4	-27.7	E.P.S.	125 PINS (SIZE OF PLUG & NO. OF PINS ARE APPROXIMATE)
19	ELECTRICAL GROUND POWER AND FUEL CELL HEATER	1 PLUG 3"DIA	AUTOMATIC	T - 5 SEC	Xs=334.0	71.4	-27.7	E.P.S.	SIZE OF PLUG APPROXIMATE NO. OF PINS UNKNOWN
20	NITROGEN FILL LINE	1/4"DIA 1500 PSI	MANUAL	T - 6 HR	Xs=291.8	73.8	-20.0	E.P.S.	
21	NITROGEN FILL VENT LINE	1/4"DIA	MANUAL	T - 6 HR	Xs=289.8	73.8	-20.0	E.P.S.	
22	GLYCOL FILL LINE	1/4"DIA	MANUAL	T - 6 HR	Xs=268.75	20.5	-73.5	E.P.S.	
23	GLYCOL FILL VENT LINE NO. 1	1/4"DIA	MANUAL	T - 6 HR	Xs=258.0	-36.5	-67.2	E.P.S.	
24	GLYCOL FILL VENT LINE NO. 2	1/4"DIA	MANUAL	T - 6 HR	Xs=258.0	-56.0	-52.0	E.P.S.	
25	GLYCOL FILL VENT LINE NO. 3	1/4"DIA	MANUAL	T - 6 HR	Xs=258.0	-70.6	-31.0	E.P.S.	
26	HYDROGEN OVERBOARD PRESSURE RELIEF	1/4"DIA	AUTOMATIC	T - 5 SEC	Xs=334.0	13.0	-75.2	E.P.S.	
27	NITROGEN OVERBOARD PRESSURE RELIEF	1/4"DIA	AUTOMATIC	T - 5 SEC	Xs=332.75	74.5	-17.5	E.P.S.	
28	OXYGEN OVERBOARD PRESSURE RELIEF	1/4"DIA	AUTOMATIC	T - 5 SEC	Xs=335.25	73.8	-20.0	E.P.S.	
29	HYDROGEN PURGE CONNECTION (FUEL CELL)	1/4"DIA	MANUAL	T - 6 HR	Xs=336.5	13.0	-75.2	E.P.S.	
30	OXYGEN PURGE CONNECTION (FUEL CELL)	1/4"DIA	MANUAL	T - 6 HR	Xs=335.25	74.5	-17.5	E.P.S.	
31	*R.C. SYSTEM OXIDIZER FILL TANK "A"	3/4"DIA	MANUAL	T - 6 HR	Xs=334.5	58.7	49.0	PROP	
32	R.C. SYSTEM OXIDIZER FILL TANK "B"	3/4"DIA	MANUAL	T - 6 HR	Xs=334.5	60.0	47.3	PROP	
33	R.C. SYSTEM OXIDIZER FILL VENT TANK "A"	1/2"DIA	MANUAL	T - 6 HR	Xs=337.0	58.7	49	PROP	
34	R.C. SYSTEM OXIDIZER FILL VENT TANK "B"	1/2"DIA	MANUAL	T - 6 HR	Xs=337.0	60.0	47.3	PROP	
35	R.C. SYSTEM FUEL FILL TANK "A"	3/4"DIA	MANUAL	T - 6 HR	Xs=334.5	-60.0	-47.3	PROP	
36	R.C. SYSTEM FUEL FILL TANK "B"	3/4"DIA	MANUAL	T - 6 HR	Xs=334.5	-58.7	-49	PROP	
37	R.C. SYSTEM HELIUM FILL TANK "A"	1/2"DIA	MANUAL	T - 6 HR	Xs=331.5	-60.0	-47.3	PROP	
38	R.C. SYSTEM HELIUM FILL TANK "B"	1/2"DIA	MANUAL	T - 6 HR	Xs=331.5	60.0	47.3	PROP	
39	R.C. SYSTEM FUEL FILL VENT TANK "A"	1/2"DIA	MANUAL	T - 6 HR	Xs=337.0	-60.0	-47.3	PROP	
40	R.C. SYSTEM FUEL FILL VENT TANK "B"	1/2"DIA	MANUAL	T - 6 HR	Xs=337.0	-58.7	-49.0	PROP	
41	S.P. SYSTEM OXIDIZER FILL	2"DIA	MANUAL	T - 6 HR	Xs=190.0	22.2	73.0	PROP	
42	S.P. SYSTEM OXIDIZER FILL VENT	1"DIA	MANUAL	T - 6 HR	Xs=331.5	58.7	49.0	PROP	
43	S.P. SYSTEM HELIUM FILL	1/2"DIA	MANUAL	T - 6 HR	Xs=334.0	-72.0	26.0	PROP	
44	S.P. SYSTEM FUEL FILL	2"DIA	MANUAL	T - 6 HR	Xs=190.0	-22.2	-73.0	PROP	
45	S.P. SYSTEM FUEL FILL VENT	1"DIA	MANUAL	T - 6 HR	Xs=331.5	-58.7	-49.0	PROP	
46	S.P. SYSTEM FUEL OVERBOARD PRESSURE RELIEF	1-1/4"DIA	AUTOMATIC	T - 5 SEC	Xs=334.0	35.0	68.1	PROP	
47	S.P. SYSTEM OXIDIZER OVERBOARD PRESSURE RELIEF	1-1/4"DIA	AUTOMATIC	T - 5 SEC	Xs=334.0	70.5	29.8	PROP	

COMMAND MODULE

FIND NO.	SERVICE CONNECTION (PURPOSE)	LINE SIZE & FITTING	DISCONNECT	T - TIME OF DISCONNECT	CENTERLINE LOCATION STATION	Y	Z	GROUP	MISCELLANEOUS
48	R.C. SYSTEM FUEL FILL	1"DIA							
49	R.C. SYSTEM FUEL FILL VENT	5/8"DIA							
50	R.C. SYSTEM OXIDIZER FILL	1"DIA							
51	R.C. SYSTEM OXIDIZER FILL VENT	5/8"DIA							
52	WATER CIRCUIT DRAIN	1/4"DIA							
53	ETHYLENE GLYCOL - H_2O GROUND COOLANT RETURN CONNECTION	2"DIA							
54	GLYCOL AIR PURGE	3/8"DIA							
55	RE-ENTRY O_2	1/4"DIA							
56	ETHYLENE GLYCOL - H_2O GROUND COOLANT SUPPLY	1/4"DIA							

* R.C. DENOTES REACTION CONTROL

Figure 5-10. Apollo Disconnect Locations

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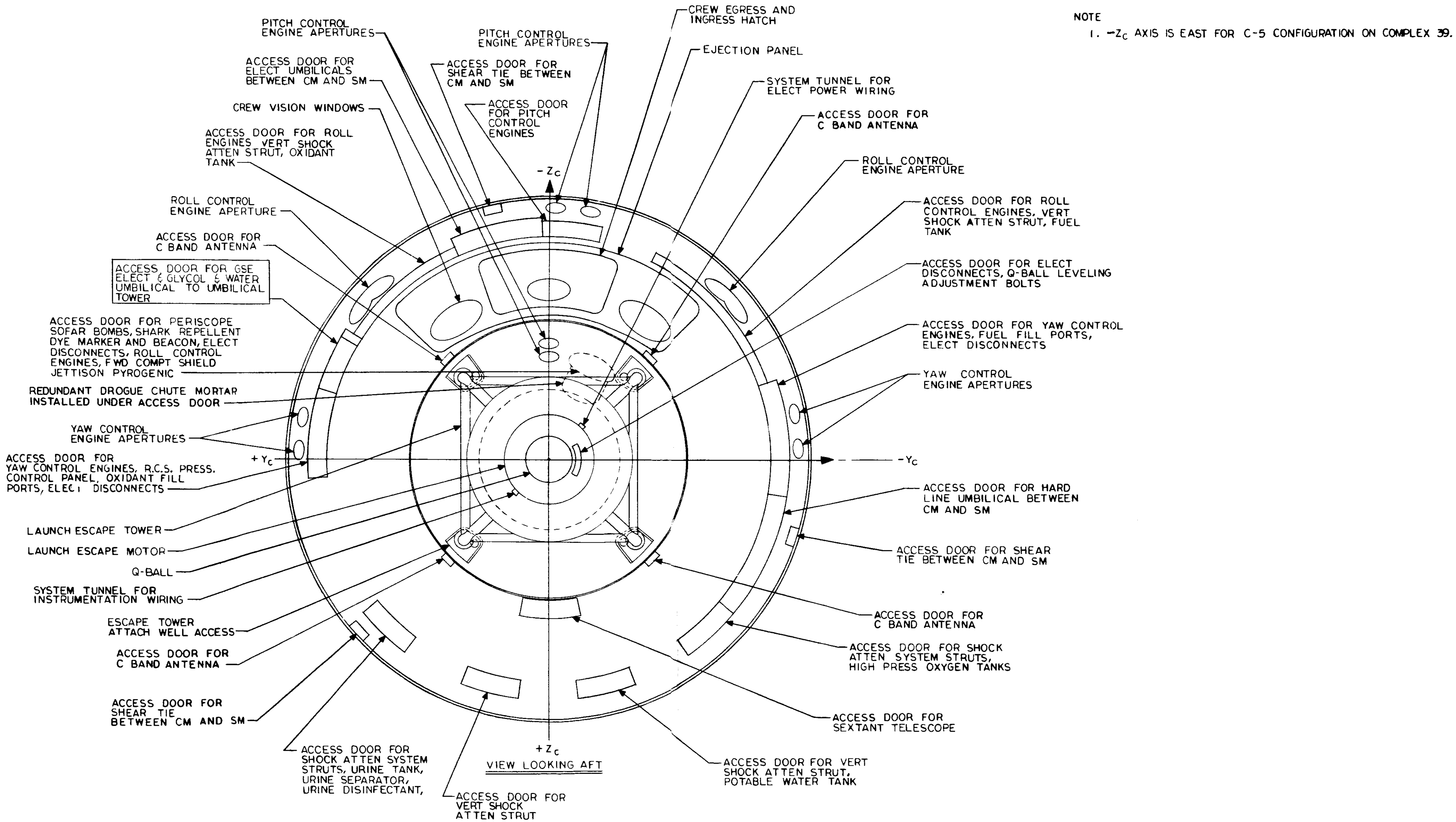

Figure 5-11. Command Module Umbilical Areas

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SERVICE MODULE

FIND NO.	FUNCTION	QUAN.	MEDIA	OPERATION PRESSURE	FLOW RATE	TEMP °F	CONNECTOR TYPE	CONNECTOR WT.	CONNECTOR SIZE	LINE TYPE WT. (LB/FT)	LINE TYPE SIZE
1	OXYGEN FILL LINE FOR TANK "A" E.C.S.	1	LO_2	50 PSI (MAX)	7.5 GPM	-287	MANUAL		3/8	0.7	3/8
2	OXYGEN FILL LINE FOR TANK "B" E.C.S.	1	LO_2	50 PSI (MAX)	7.5 GPM	-287	MANUAL		3/8	0.7	3/8
3	HYDROGEN FILL LINE FOR TANK "A" E.C.S.	1	LH_2	50 PSI (MAX)	7.5 GPM	-408	MANUAL		3/8	0.651	3/8
4	HYDROGEN FILL LINE FOR TANK "B" E.C.S.	1	LH_2	50 PSI (MAX)	7.5 GPM	-408	MANUAL		3/8	0.651	3/8
5	NITROGEN FILL LINE FOR TANK "A" E.C.S.	1	LN_2	50 PSI (MAX)	3 GPM	-320	MANUAL		1/4	0.48	1/4
6	NITROGEN FILL LINE FOR TANK "B" E.C.S.	1	LN_2	50 PSI (MAX)	3 GPM	-320	MANUAL		1/4	0.48	1/4
7	OXYGEN VENT LINE FOR TANK "A" E.C.S.	1	LO_2	NA	NA	-60 TO -287	MANUAL		3/4	0.45	3/4
8	OXYGEN VENT LINE FOR TANK "B" E.C.S.	1	LO_2	NA	NA	-60 TO -287	MANUAL		3/4	INCL. IN ITEM 7	3/4
9	HYDROGEN VENT LINE FOR TANK "A" E.C.S.	1	LH_2	NA	NA	-260 TO -408	MANUAL		3/4	0.50	3/4
10	HYDROGEN VENT LINE FOR TANK "B" E.C.S.	1	LH_2	NA	NA	-260 TO -408	MANUAL		3/4	INCL. IN ITEM 9	3/4
11	NITROGEN VENT LINE FOR TANK "A" E.C.S.	1	LN_2	NA	NA	-90 TO -320	MANUAL		1/2	0.22	1/2
12	NITROGEN VENT LINE FOR TANK "B" E.C.S.	1	LN_2	NA	NA	-90 TO -320	MANUAL		1/2	INCL. IN ITEM 11	1/2
13	WATER FILL LINE E.C.S.	1	H_2O	3 PSI	NA	60	MANUAL		1/4	0.18	1/4
14	WATER-GLYCOL FILL LINE E.C.S.	1	H_2O-GLYCOL	TBD	NA	70	MANUAL		1/4	0.18	1/4
15	WATER-GLYCOL VENT LINE E.C.S.	1	H_2O-GLYCOL		NA	AMBIENT	MANUAL		1/4	0.18	1/4
16	HYDROGEN OVERBOARD PRESSURE RELIEF E.C.S.	1	LH_2	TBD	NA	-260 TO -408	AUTO		1/4	INCL. IN ITEM 9	1/4
17	NITROGEN OVERBOARD PRESSURE RELIEF E.C.S.	1	LN_2	TBD	NA	-90 TO -320	AUTO		1/4	INCL. IN ITEM 11	1/4
18	ELECTRICAL GROUND CHECKOUT E.P.S.	2	—	—	—	—	AUTO		3"		
19	ELECTRICAL GROUND POWER AND FUEL CELL HEATER E.P.S.	1	—	—	—	—	AUTO		3"		
20	NITROGEN FILL LINE E.P.S.	1	LN_2	1500 PSI	TBD	-320	MANUAL		1/4	0.48	1/4
21	NITROGEN VENT LINE E.P.S.	1	LN_2	TBD	NA	-90 TO -320	MANUAL		1/4	INCL. IN ITEM 11	1/4
22	WATER GLYCOL FILL LINE — EQUIPMENT BAY E.P.S.	1	H_2O-GLYCOL	TBD	TBD	70	MANUAL		1/4	0.18	1/4
23	WATER GLYCOL VENT LINE #1 — RADIATOR E.P.S.	1	H_2O-GLYCOL	TBD	NA	70	MANUAL		1/4	0.18	1/4
24	WATER GLYCOL VENT LINE #2 — RADIATOR E.P.S.	1	H_2O-GLYCOL	TBD	NA	70	MANUAL		1/4	0.18	1/4
25	WATER GLYCOL VENT LINE #3 — RADIATOR E.P.S.	1	H_2O-GLYCOL	TBD	NA	70	MANUAL		1/4	0.18	1/4
26	HYDROGEN OVERBOARD PRESSURE RELIEF E.P.S.	1	LH_2	TBD	NA	-260 TO -408	AUTO		1/4	INCL. IN ITEM 9	1/4
27	NITROGEN OVERBOARD PRESSURE RELIEF E.P.S.	1	LN_2	TBD	NA	-90 TO -320	AUTO		1/4	INCL. IN ITEM 11	1/4
28	OXYGEN OVERBOARD PRESSURE RELIEF E.P.S.		LO_2	TBD	NA	-60 TO -287	AUTO		1/4	INCL. IN ITEM 7	1/4
29	HYDROGEN PURGE CONNECTION (FUEL CELL) E.P.S.	1	LH_2	TBD	TBD	TBD	MANUAL		1/4	0.07	1/4
30	OXYGEN PURGE CONNECTION (FUEL CELL, OXYGEN SUPPLY) E.P.S.	1	LO_2	TBD	TBD	TBD	MANUAL		1/4	0.07	1/4
31	RCS OXIDIZER FILL TANK "A" PROP.	1	NTO	TBD	TBD	70 ± 5	MANUAL		3/4	1.59	3/4
32	RCS OXIDIZER FILL TANK "B" PROP.	1	NTO	TBD	TBD	70 ± 5	MANUAL		3/4	1.59	3/4

SERVICE MODULE (CONT'D)

FIND NO.	FUNCTION	QUAN.	MEDIA	OPERATION PRESSURE	FLOW RATE	TEMP °F	CONNECTOR TYPE	CONNECTOR WT.	CONNECTOR SIZE	LINE TYPE WT. (LB/FT)	LINE TYPE SIZE
33	RCS OXIDIZER VENT TANK "A" PROP.	1	NTO	NA	NA	NA	MANUAL		1/2	1.16	1/2
34	RCS OXIDIZER VENT TANK "B" PROP.	1	NTO	NA	NA	NA	MANUAL		1/2	1.16	1/2
35	RCS FUEL FILL TANK "A" PROP.	1	UDMH-HYDRAZINE	TBD	TBD	70±5	MANUAL		3/4	1.42	3/4
36	RCS FUEL FILL TANK "B" PROP.	1	UDMH-HYDRAZINE	TBD	TBD	70±5	MANUAL		3/4	1.42	3/4
37	RCS HELIUM FILL TANK "A" PROP.	1	HELIUM	4500 PSI	2.7 CFM	60	MANUAL		1/2	0.6	1/2
38	RCS HELIUM FILL TANK "B" PROP.	1	HELIUM	4500 PSI	2.7 CFM	60	MANUAL		1/2	0.6	1/2
39	RCS FUEL VENT TANK "A" PROP.	1	UDMH-HYDRAZINE	NA	NA	NA	MANUAL		1/2	1.03	1/2
40	RCS FUEL VENT TANK "B" PROP.	1	UDMH-HYDRAZINE	NA	NA	NA	MANUAL		1/2	1.03	1/2
41	SPS OXIDIZER FILL PROP.	1	NTO	25 PSI ABOVE VAPOR PRESS.	60 GPM	70±5	MANUAL		2	6.87	2
42	SPS OXIDIZER VENT PROP.	1	NTO	NA	NA	NA	MANUAL		1"	1.59	1"
43	SPS HELIUM FILL PROP.	1	HELIUM	4500 PSI	2.7 CFM	60	MANUAL		1/2	0.81	1/2
44	SPS FUEL FILL PROP.	1	UDMH HYDRAZINE	25 PSI ABOVE VAPOR PRESS.	50 GPM	70±5	MANUAL		2	6.10	2
45	SPS FUEL VENT PROP.	1	UDMH-HYDRAZINE	NA	NA	NA	MANUAL		1	1.42	1
46	FUEL OVERBOARD PRESSURE RELIEF PROP.	1	UDMH-HYDRAZINE	TBD	NA	NA	AUTO		1-1/4	1.172	1-1/4
47	SPS OXIDIZER OVERBOARD PRESSURE RELIEF PROP.	1	NTO	TBD	NA	NA	AUTO		1-1/4	1.172	1-1/4

COMMAND MODULE

FIND NO.	FUNCTION	QUAN.	MEDIA	OPERATION PRESSURE	FLOW RATE	TEMP °F	CONNECTOR TYPE	CONNECTOR WT.	CONNECTOR SIZE	LINE TYPE WT. (LB/FT)	LINE TYPE SIZE
48	RCS FUEL FILL PROP.	1	UDMH-HYDRAZINE	TBD	TBD	70±5	MANUAL		1	1.42	1
49	RCS FUEL VENT PROP.	1	UDMH-HYDRAZINE	NA	NA	NA	MANUAL		5/8	1.17	5/8
50	RCS OXIDIZER FILL PROP.	1	NTO	TBD	TBD	70±5	MANUAL		1	1.59	1
51	RCS OXIDIZER VENT PROP.	1	NTO	NA	NA	NA	MANUAL		5/8	1.33	5/8
52	WATER CIRCUIT DRAIN E.C.S.	1	H_2O	3 PSI	NA	AMBIENT	MANUAL		1/4	NO GSE PANEL	1/4
53	WATER GLYCOL GROUND COOLANT RETURN E.C.S.	1	H_2O-GLYCOL	50 PSI	250 LB. PER HR.	NA	AUTO		2		2
54	GLYCOL AIR PURGE E.C.S.	1	GLYCOL-AIR	TBD	TBD	TBD	MANUAL		3/8	0.65	3/8
55	REENTRY O_2 E.C.S.	1	O_2	7500 PSI	TBD	70	MANUAL		1/4	0.66	1/4
56	WATER GLYCOL GROUND COOLANT SUPPLY E.C.S.	1	H_2O-GLYCOL	50 PSI	250 LB. PER HR.	45	AUTO		1/4	0.18	1/4

Figure 5-12. Apollo Service Requirements

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pressurizing the propellant tanks.

Cryogenic fluid servicing is required for the Service Module as listed. Liquid hydrogen, liquid oxygen, and liquid nitrogen tanks are housed in the Service Module. Remotely operated disconnects are presently planned for the hydrogen, nitrogen, and oxygen overboard pressure relief. Gaseous purging of the cryogenic tanks and systems will be done through the fill connect points.

The cooling system aboard the spacecraft will require servicing. The disconnects for filling and venting the water-glycol coolant and helium are located in the Service Module. The water-glycol supply and return disconnects for the ground cooling system are located in the Command Module. These are remotely operated disconnects. Potable water tank fill disconnects are located in the Service Module. Gaseous purging of the above systems will be accomplished through the fill disconnects.

Individual access arms will be required for servicing the Service Module and the Command Module as shown in figure 5-13.

The arms for servicing the Service Module shall have the following capabilities: suitable servicing access for the items listed in figure 5-12. (This implies sufficient space for a man to connect and disconnect fluid servicing lines and to open access doors for servicing and inspection when and if required); sufficient space for extension and retraction of antennas in the Service Module; sufficient space for all the

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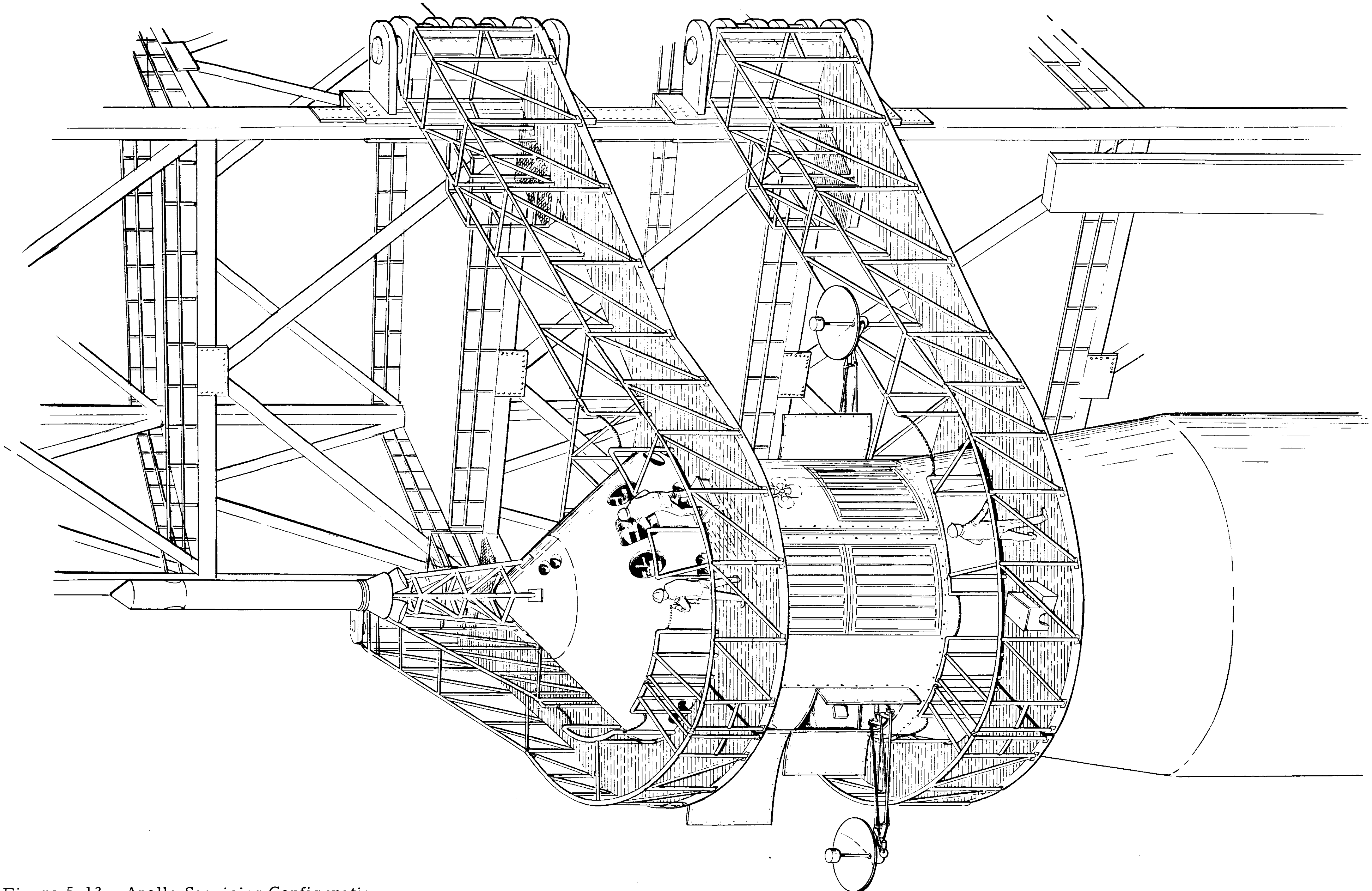

NOTES:
1. APPROXIMATE 30-INCH GAP BETWEEN VEHICLE AND ARMS FOR SWAY CLEARANCE NOT SHOWN.
2. ORIENTATION OF SERVICE MODULE ANTENNAS NOT NECESSARILY CORRECT WITH RESPECT TO TOWER.

Figure 5-13. Apollo Servicing Configurations

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fluid servicing lines and electrical cables plus vicinity equipment if required.

The arms for servicing the Command Module shall have the following capabilities: "white room" capabilities for crew-members ingress through the hatch; suitable servicing access for the items listed in figure 5-12. (This implies sufficient space for a man to connect and disconnect fluid servicing lines and to open access doors for servicing and inspection when and if required.); sufficient space for all the fluid servicing lines and electrical cables plus spacecraft vicinity equipment.

Due to the large masses involved in the access arms, it may be necessary to use a separate service arm for the remote automatic disconnects listed in figure 5-12, to obtain a satisfactory arm retraction time. The remote disconnects for the Service Module and Command Module could be attached to this arm.

Possible misalignment of the vehicle and tower can be obtained from curves in Section VI.

Many of the servicing requirements for the Apollo spacecraft are not firm at this time; therefore, changes may be expected in the future.

Time for remote disconnect for the Service Module and Command Module referred to as prelaunch, is not yet firmed. This may be changed to lift-off.

G. FUTURE STAGES

1. Lunar Excursion Module.

The proposed Lunar Excursion Module, in all probability, would be serviced through the aft adapter of the Apollo Service Module.

Service requirements for the LEM are not determinable as of this date. There are two possibilities for propelling the module: either with LOX and liquid hydrogen, or with hypergols. Either system of fueling would require a service arm and might or might not require that umbilicals be maintained until lift-off.

The Service and Command Modules would be propelled into a lunar orbit, where separation of the Lunar Excursion Module would occur. After separation, the Lunar Excursion Module, carrying two men, would descend to the surface of the moon. After completion of that phase of the mission on the surface of the moon, part of the module would return, under its own power, to rendezvous with the orbiting Service Module/Command Module combination. After this rendezvous, the astronauts would transfer back into the Command Module for the return, direct-reentry voyage to Earth.

2. Nuclear and Rift Stages.

A situation exists in resolving service requirements for the Nuclear stage similar to that for the LEM stage. The Nuclear stage mounted above the S-II stage is to be propelled by liquid

hydrogen and would, according to existing ground rules at Cape Canaveral, require an umbilical arm(s), if only for the purpose of hydrogen venting. Auxiliary service and fluid requirements are unknown as of this writing other than a need for propellant fill and venting. A possible configuration and umbilical arrangement is shown in figure 4-7. Wind deflection cannot be determined at this time.

SECTION VI

OPERATIONAL REQUIREMENTS

A. VEHICLE DRIFT CURVE STUDY

A study performed by the MSFC Aeroballistic Division gives the drift effect of thrust variations, thrust misalignment for 99 percent wind gusts at 85 feet, and the root sum square of these influences. Figure 6-1 shows the curve. The plot of the arithmetic sums of the component influences, and the time marks are added for the convenience of the user. A thrust/weight ratio of 1.25/1 is assumed. The same information is shown pictorially in figure 6-2.

B.. UMBILICAL LOCATIONS WITH RESPECT TO LAUNCH TOWER FACILITY.

Approximate locations of umbilical arms and umbilical connections for four representative vehicle configurations are shown in figure 4-1. Minor modifications of locations shown must be expected as detail design of the stages progresses. As modified and substitute stages are introduced above the S-II stage, wide variations in umbilical elevations will be required.

It is possible, that in the future, it will be desireable to launch vehicles other than the presently forseen C-5 configurations from the Complex 39 Transporter-Launcher. Accordingly, it is recommended that the tower be designed to permit umbilical arms to be installed at

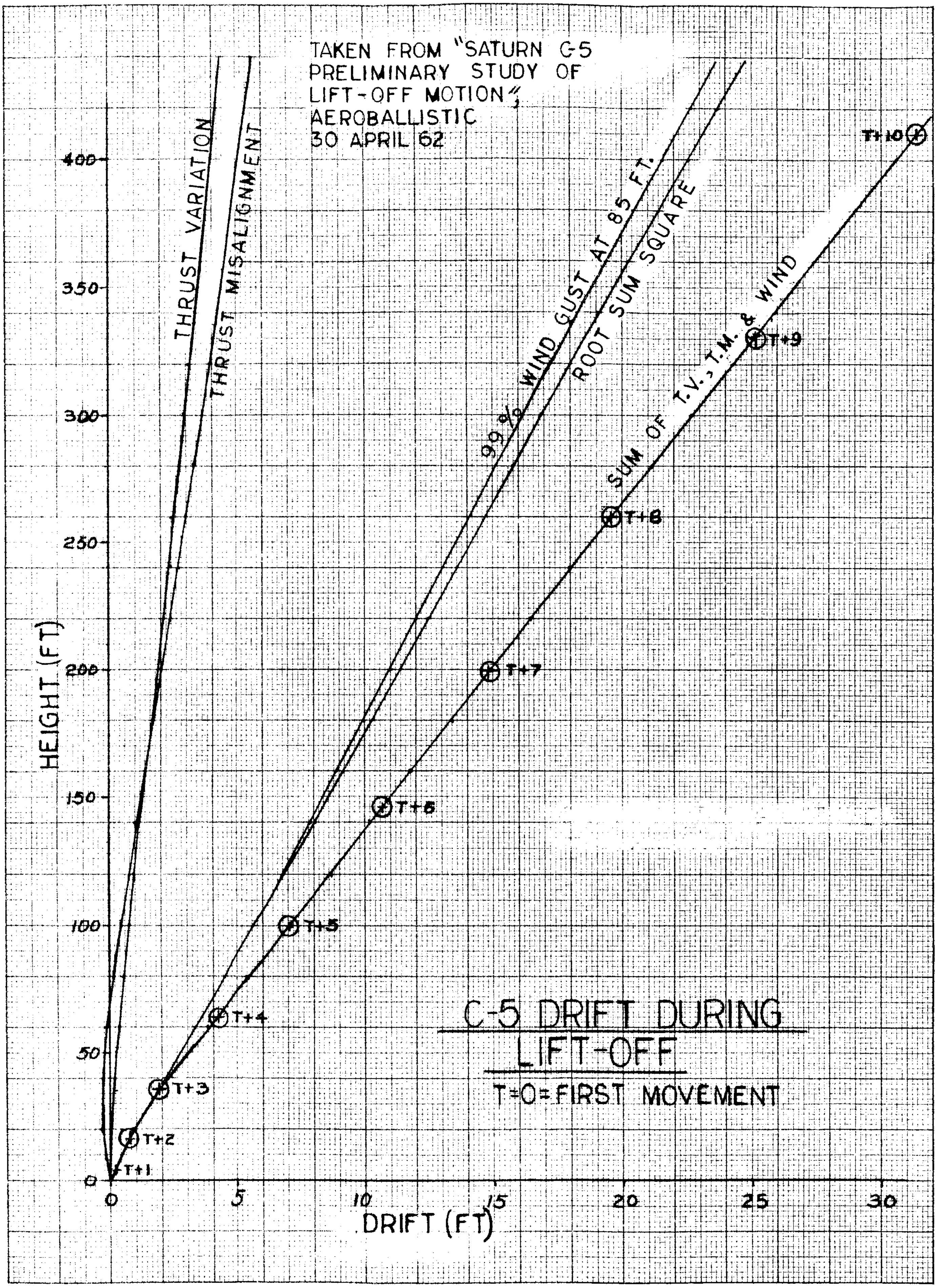

Figure 6-1. C-5 Drift During Lift-Off

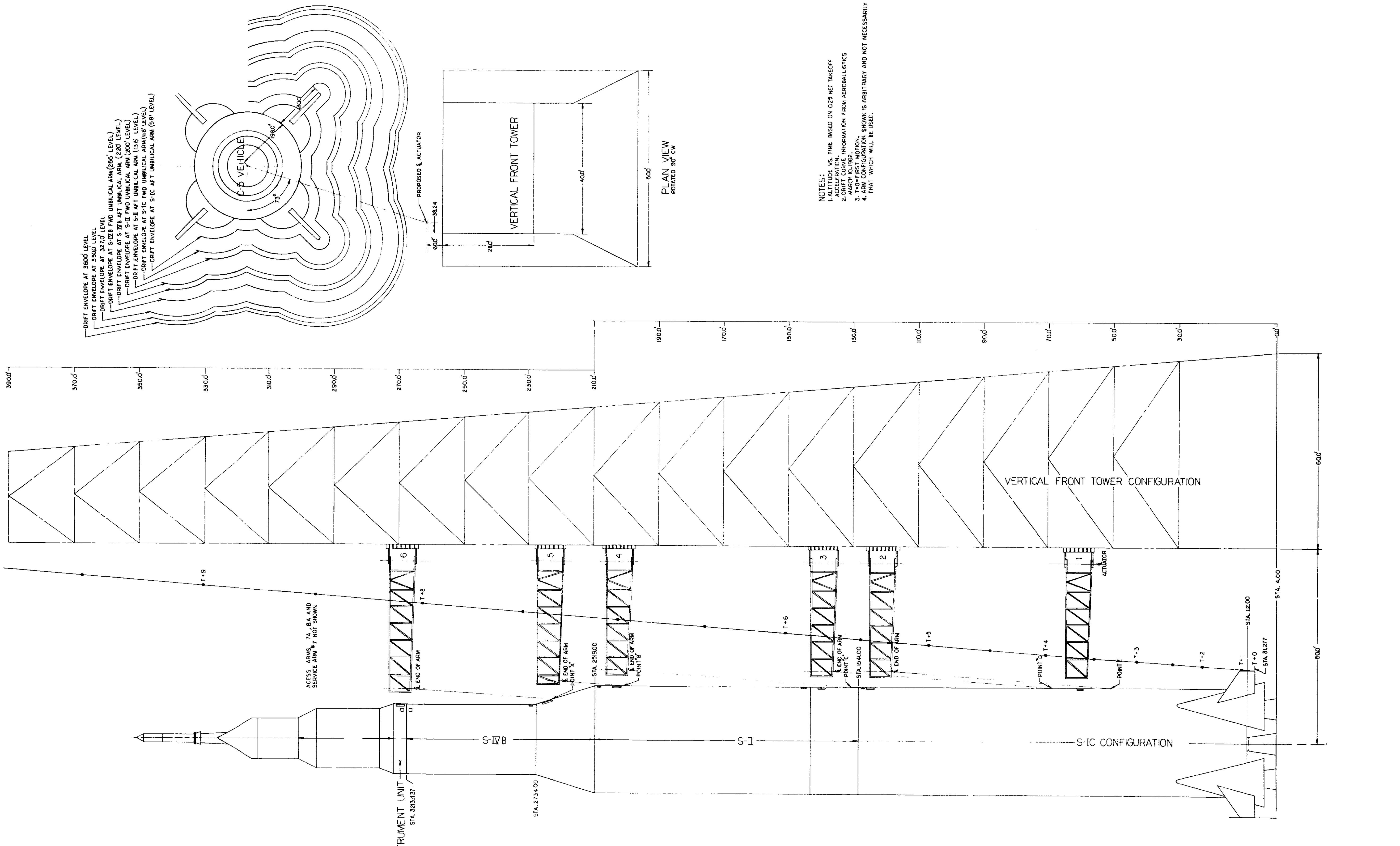

Figure 6-2. C-5 Drift Envelope

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any desired level between 50 and 370 feet above the launch deck in convenient increments. Flexibility must be provided to accomodate both vertical and horizontal motion between vehicle and tower. The nature and magnitudes of these motions are discussed in paragraphs D. and E. of this section.

C. UMBILICAL DISCONNECT AND RETRACT SYSTEM

In considering the optimum umbilical disconnect and retract system for the Saturn C-5, the objectives should be defined.

The primary objective is a successful mission. Lacking success, a safe failure, without injury to personnel or damage to the vehicle or ground equipment is preferred. Lacking a safe failure, it is desired to know where, how, and why failure occurred, in order that the fault may be corrected in the future. Damage or destruction of vehicle or ground equipment is,in every case,secondary to personnel safety.

The umbilical disconnect and retract systems are critical factors in the accomplishment of our objectives. Selection of the optimum system is complicated by the following conflicting factors:

1. In order that a launch not be attempted unless all vehicle systems are operating properly, it is necessary that system monitoring be maintained as long as possible. This implies lift-off disconnect of monitoring systems.

2. In order that recycle time for a second launch attempt

following an abort be maintained, it is desirable that remotely controlled rapid defueling or retopping of propellant tanks be possible at any time short of hold-down release. This implies either lift-off propellant line disconnect or early disconnect with remotely controlled reconnect capability. The same capability would be required for propellant tank monitoring system connection. (Vent line connections for cryogenic fuels must be maintained until lift-off.)

3. In order that factors adversely affecting launch reliability be minimized, it is desirable that all connections be released, retracted, and confirmed prior to lift-off.

Considerable attention has been devoted to disconnect and reconnect capability for those services necessary, to allow remote defueling. The originally-stated ground rules specified lift-off disconnection. Very recently a tentative change in ground rules was made which requires that those umbilical connections necessary to maintain and/or restore the vehicle to a safe condition, in the event of an abort, be of the lift-off disconnect type.

The reason for considering a reconnect capability, is the possibility of an abort after release of propellant lines but prior to hold-down release, a period of one second. The probability of this is extremely remote.

In the event of an abort, the coupled hydrogen vent line provides

a means for the liquid hydrogen to be allowed to boil away safely (Appendix A, Memorandum M-P&VE-VG-84, paragraph 20). Thus, the recycle time to prepare for another launch attempt is the only consideration in propellant recoupling. There is no question that a reconnect system could be developed. It is questionable, however, whether the ability to reconnect offers any real advantage. A remotely operated reconnect system must impose cost and complexity penalties on the basic structure and retract system of the umbilical arms. As an example, conflict lies in the need for arms freedom to permit relative motion between the umbilical tower and the vehicle, and the need for rigidity or controlled motion of arms with respect to tower to allow reconnect alignment actuation. Reliability effect on the disconnect will have to be determined.

The abort-recycle time may, in the space-rendezvous programs, be a very critical consideration, unless stand-by vehicles are provided. Until such rendezvous are attempted, recycle time represents a delay but does not represent a risk of human life or wasteful loss of space vehicle.

Considering all of the foregoing factors, it is recommended that:

a. For the present, neither remote reconnect capabilities nor provisions for their addition be required of umbilical connections or umbilical arms. Umbilical area space requirements for future

reconnects should be considered in vehicle design.

b. A design and development program be initiated, directed toward establishing firm criteria for remotely controlled connections, and techniques for accomplishment. It is suggested that problems and solutions involved are essentially common to those involved in space transfer of fuel, etc. and that the program should be approached from a basic, rather than specific, standpoint.

D. VEHICLE LENGTH VARIATION

Appreciable changes in the length of the C-5 vehicle occur due to load and temperature changes.

Four conditions define the limits, as follows:

1. Sum of nominal stage lengths as manufactured (ambient conditions-empty).

2. Sum of stage lengths assembled (ambient conditions - empty).

3. Sum of stage lengths assembled (longest condition) (Florida sunshine - empty tanks-pressurized).

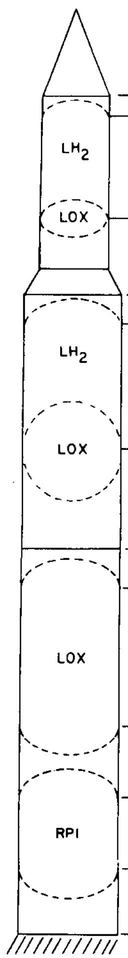
4. Sum of stage lengths assembled (shortest condition) (nominal ambient day - overcast-fueled.)

Figures 6-3, and 6-4 present the deviations of actual stations with respect to nominal under the various conditions.

E. WIND AND PRESSURE PROFILES

Data on figure 6-5 has been used to plot curves in figures 6-6 and 6-7.

Figure 6-3. Vehicle Length Variations Due to Load and Temperature Changes - Graph



Stage	Nominal Lengths	Sun Load Skin Temp 120°F	Dead Load	Temp of Cold Liquid Fuels	Weight of Fuel Above	Pressure of Tanks at Fill	Pressure of Tanks at Standby	Max in Sun Unloaded Fill Pressure	Min Cloudy Day Loaded Standby Press
S-IVB	708.55 (311)	+2.06 / +.467	-.2109 / -.0178	-5.48 / -1.18	-1.614 / -.0232	+.761 / +.0722	+.6051 / +.0361	+2.638 / +.5214	-6.639 / -1.185
S-II	978: 579	+1.593 / +.408	-.1931 / -.0502	-4.30 / -2.30	-1.591 / -.0755	+.689 / +.510	+.569 / +.510	+2.117 / +.8678	-5.454 / -1.916
	359	+1.185 / +.237	-.1429 / -.0250		-1.515 / -.173			+1.2491 / +.212	-3.538 / -.198
S-IC	1437: 121	+.948 / +.080	-.1179 / -.0190		-1.342 / -.056			+1.0371 / +.071	-3.340 / -.075
	525	+.868 / +.346	-.0989 / -.0404	-2.00 / -2.00	-1.286 / -.192	+.197 / +.197	+.059 / +.059	+.9661 / +.5026	-3.326 / -2.173
	270	+.522 / +.178	-.0585 / -.0285		-1.094 / -.496			+.4635 / +.1495	-1.153 / -.5245
	279	+.344 / +.184	-.030 / -.0214		-.598 / -.372			+.3140 / +.1626	-.628 / -.3984
	242	+.160 / +.160	-.0086 / -.0086		-.226 / -.226			+.1514 / +.1514	-.2346 / -.2346
Total	3123								

Legend
Deflection
A — Accumulated Deflection at A from S-IC Support
B — Increment of Deflection Between A & B

Note: Blank Areas not Applicable to the Column Condition.

Figure 6-4. Vehicle Length Variations due to Load and Temperature Changes - Tabulation

Vehicle Survival (Self Supporting) (99.9% of strongest Wind month)

H (Ft) 1	V (Knots) 1 Steady State Wind	V (Knots) 1 (Peak Wind)	Vehicle P (PSF) 2 Steady State Wind	Vehicle P (PSF) 2 Peak Wind	Tower P (PSF) 3 Steady State Wind	Tower P (PSF) 3 Peak Wind
10	23.0	32.2	1.894	2.804	3.712	5.496
30	28.8	40.3	2.969	4.396	5.814	8.608
60	33.6	47.0	4.042	5.984	7.908	11.708
100	37.5	52.5	5.035	7.543	9.868	14.608
200	42.6	59.6	6.497	9.618	12.717	18.827
300	46.0	64.4	7.575	11.215	14.848	21.981
400	48.3	67.6	8.352	12.364	16.360	24.220

Launch Wind. 99% of Strongest Wind Month

H (Ft) 1	V (Knots) 1 Steady State Wind	V (Knots) 1 Peak Wind	Vehicle P (PSF) 2 Steady State Wind	Vehicle P (PSF) 2 Peak Wind	Tower P (PSF) 3 Steady State Wind	Tower P (PSF) 3 Peak Wind
10	18.4	25.8	1.212	1.795	2.383	3.528
30	22.9	32.1	1.877	2.779	3.689	5.461
60	26.4	36.9	2.495	3.694	4.875	7.216
100	29.3	41.0	3.073	4.550	6.018	8.909
200	33.6	47.0	4.042	5.984	7.908	11.708
300	36.5	51.1	4.770	7.061	9.348	13.839
400	38.7	54.2	5.363	7.938	10.517	15.569

1. From M-P&VE-VA-28 (Glover - 4/10/62)

2. $P = .0027\ V^2\ (\text{mph}) = .0027 \times (\frac{6080}{5280}\ V\ \text{knots})^2$ for cylindrical bodies.

3. $P = .004\ V^2\ (\text{mph}) = .004 \times (\frac{6080}{5280}\ V\ \text{knots})^2$ for flat plates.

Figure 6-5. Wind and Pressure Profile Date

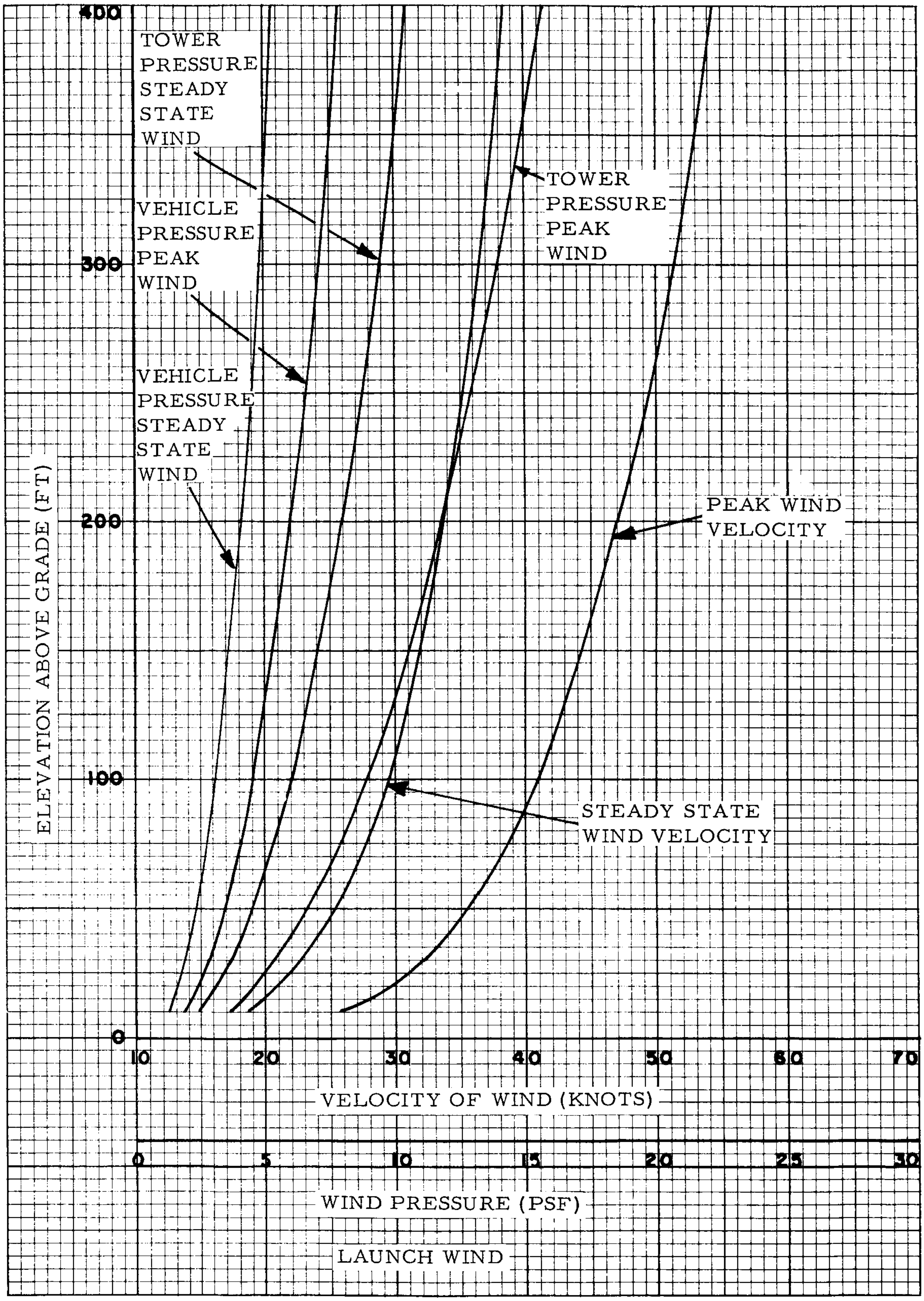


Figure 6-6. Launch Wind Pressure Profiles

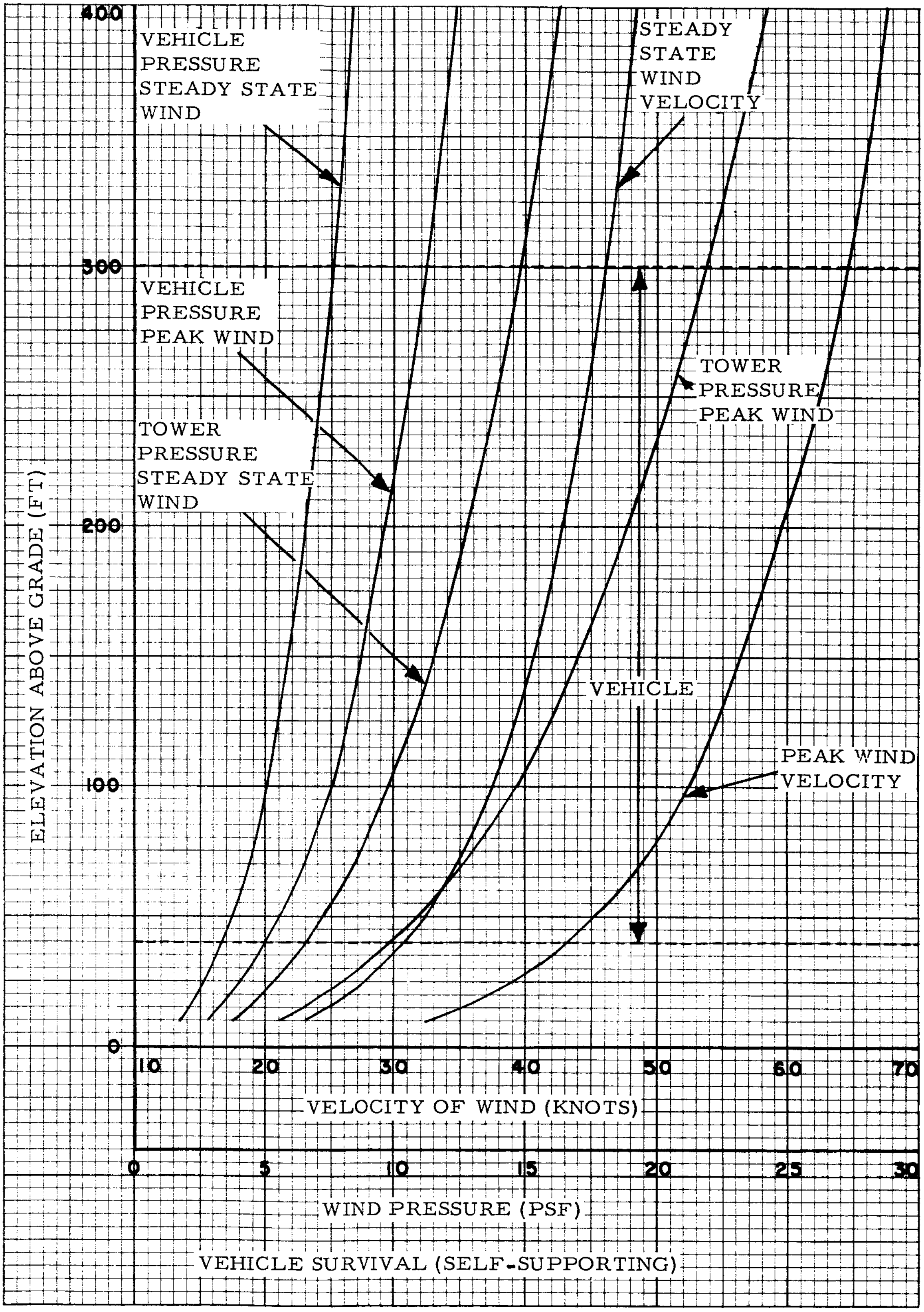


Figure 6-7 Survival Wind Pressure Profiles

F. VEHICLE DEFLECTION

1. Deflection Due to Wind.

The C-5 vehicle will deflect as a cantilever beam of varying moment of inertia, and with a load varying due to both the wind velocity profile and the local diameter of the vehicle. Figure 6-8 presents the moments of inertia distribution, maximum steady state and peak wind load distributions, and deflections of the vehicle. Derivation of this data will be found in Appendix A.

2. Vehicle Deflection Due to Solar Heating.

A bending of the vehicle will occur due to assymetrical expansion of the vehicle under solar radiation.

The direction and magnitude of this deflection will be affected by such presently undefined factors as the heat transfer characteristics of the internal structure of the vehicle, the position of the sun, cooling effects of wind, etc.

The vehicle, in general, will lean away from the sun. Assuming a 50°F skin temperature differential between the sun and shaded sides of the vehicle, deflections of 2.42 and 7.04 inches will occur at the forward ends of the S-II and S-IVB stages, respectively. Calculations will be found in Appendix A.

G. TOWER DEFLECTION

The umbilical tower, being a trussed structure, will have deflections greater than would be predicted by consideration as a cantilever

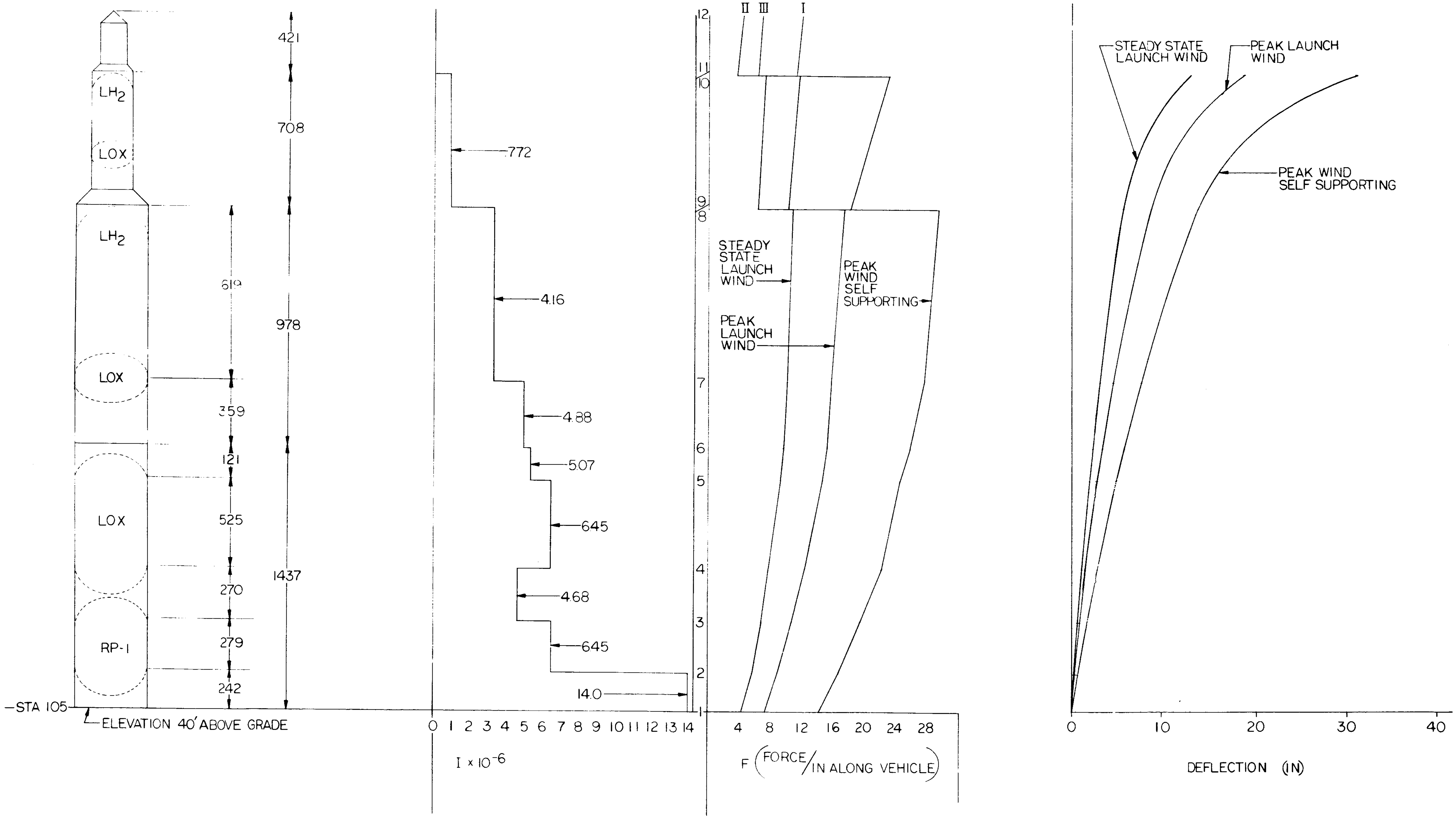


Figure 6-8. Moments of Inertia, Wind Loads and Deflections of C-5 Vehicle

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beam of equivalent EI. Deflections may be determined by a "Williot" diagram or similar technique for the particular structure designed. Theoretically, and desired degree of rigidity less than that of a cantilever of the same EI distribution can be obtained, depending on the size and distribution of shear bracing members. Factors entering into actual rigidity also involves the individual EI's of the main members, relative joint fixity, etc. Figure 6-9 shows a deflection curve based on an assumed tower and wind load.

1. Vehicle Vibration.

Preliminary estimates of 0.84 cps empty and 0.33 cps loaded for the C-5 tanking mode are the only information presently available on the natural frequencies of vibration of the vehicle (Appendix A).

2. Subjective Considerations.

In the design of the umbilical arms, connections, etc, the various factors of relative vehicle and tower motion are essential considerations. Design of every detail to accommodate the sum of the worst cases, however, is not warranted.

The following tabulation covers some of the most important conditions:

a. The inertias of the vehicle and tower are so great that the maximum deflections based on gust loadings cannot be attained.

b. The relative sizes of the vehicle and tower are such that gusts will tend to produce local rather than distributed loads, and

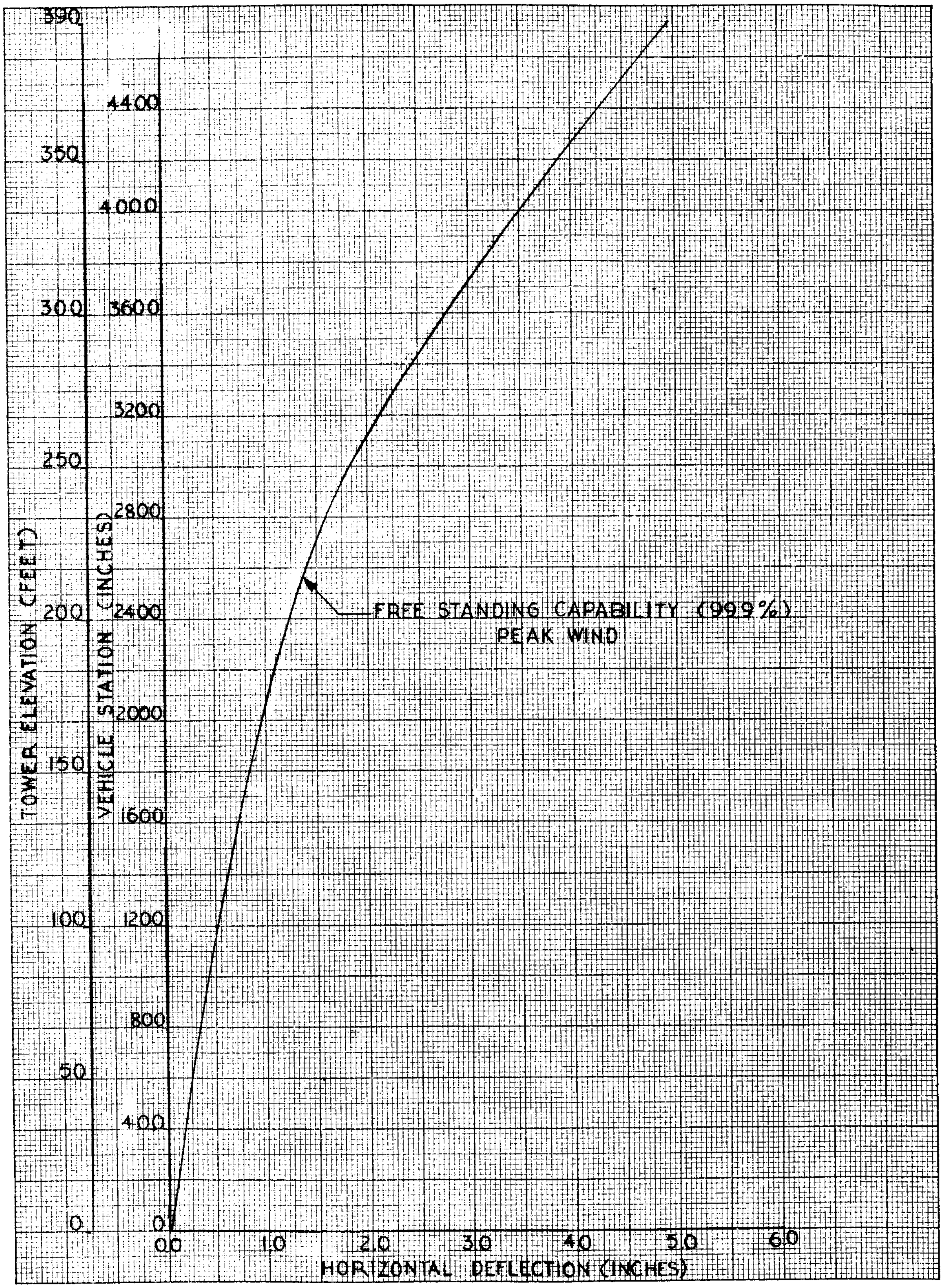

Figure 6-9. Wind Load Deflections of an Assumed Umbilical Tower

that turbulence will tend to cause such loads to counterbalance each other.

c. Prevailing wind directions under steady state loads on the vehicle and tower in close proximity to each other will be the same, and in general, they will deflect in the same direction under steady state loads.

d. Gusts will tend to produce oscillations of an amplitude which is a function of the difference of the squares of the steady state and peak wind velocities. Neglecting a. and b. above, the maximum half-amplitude of the oscillations would be equal to the difference between the steady state and peak gust deflections as shown in figure 6-8.

SECTION VII

STRUCTURE AND FUNCTION

A. GENERAL

In this text, all arms which connect the umbilical tower to the C-5 vehicle are referred to as umbilical arms. Those arms which provide 360-degree access to the Apollo spacecraft are called access arms; all other arms are given the general designation service arms. It is necessary that such arms as carry fluid lines or circuits necessary for vehicle safety remain connected until vehicle lift-off. For the presently contemplated combinations of stages, the arms which must remain connected on this basis are the upper service arms for the S-II and S-IVB stages. At lift-off, these arms must first disconnect from the vehicle, and then retract to clear the drift envelop. The required rate of retraction is, of course, dictated by the relative location of the first critical point on the vehicle to the end of the service arm.

All arms, other than the two mentioned above may, until otherwise decided, be disconnected and retracted prior to vehicle release, and should be disconnected and retracted at the earliest moment that the services carried can be dispensed with. The arm servicing the S-IC intertank area, which provides personnel access, should, if possible be retracted concurrently with personnel evacuation of the

transporter-launcher.

Failure of any of the prelaunch arms to disconnect and retract properly will result in an aborted launch. Failure of an arm carrying lift-off umbilical services to disconnect and retract properly will result in serious damage to equipment and possibly in catastrophic failure.

The highest degree of reliability must be designed into the umbilical disconnect and arm retraction mechanisms. Reliability can be increased by utilization of the simplest possible systems, and by provision of one or more degrees of redundancy.

For those arms which can be dispensed with prior to lift-off, disconnect and retract commands should be incorporated in the automatic countdown sequence, and an automatic hold initiated unless a retract-completed (or retract-initiated signal, as applicable) is received at the proper time.

For those arms which must remain until lift-off, or so nearly that retract confirmation is impossible before vehicle release, secondary and even tertiary systems of release and retract should be provided.

Apollo access arms would be retracted prior to lift-off; consequently, they offer no possibility of interfering with the vehicle's flight.

Shock absorbers, mounted on the tower, would absorb any impact and should aid in bringing the arms to a stop without damage. Positive latching devices should secure the arms against the tower after retraction. Auxiliary supports, mounted on the tower, would help support the arms when retracted.

The mechanism which causes umbilical arm retraction is called the actuator. In the primary system, the actuator's main function is to move the umbilical arm out of a collision path with the vehicle. This actuator should act as a brake in cushioning the arm's stop. Additional studies of various actuators are included.

Investigations of the service arm structure were made using two of the more heavily loaded arms (S-II and S-IVB aft). Maximum torque requirements for retraction have been determined from them. Design studies were made to determine a basic arm size and strength. This basic arm would be used in every position where a service arm is required. An extension to the basic arm would be added where needed.

These service arms must terminate a minimum of 60 inches from the vehicle. Retractable platforms on the ends of the arms provide a walkway to the vehicle.

B. COMPARATIVE EVALUATION OF UMBILICAL ARM RETRACTION GEOMETRIES AND ACTUATION METHODS

As studies progressed on the factors involved in umbilical

disconnect and retraction, the stage contractor representatives questioned whether the horizontally-swinging umbilical arm, its centerline running through the vehicle axis and powered by a hydraulic rotary actuator at the swing axis, would be the optimum for the purpose. Several alternative approaches have been considered. Although interrelated, the retraction geometry and the actuating methods must be considered independently, since any basic operating geometry could be driven by any of many actuating systems. For the purposes of structural design studies, the horizontally-swinging motion, employing a rotary actuator, is used.

1. Umbilical Arm Retraction Geometry.

A number of arm retraction geometries were considered and compared. The basic principles of operation of each are shown in figure 7-1. Figure 7-2 and 7-3 present the comparative engineering data for each geometry. Based on these figures, it is the recommendation of the stage contractors' representatives that the basic geometry shown as Case B be followed. Computations supporting figures 7-2 and 7-3 will be found in Appendix B.

2. Umbilical Arm Actuation Methods.

Arm actuation methods considered are presented in figure 7-4. Figure 7-5 presents their advantages and disadvantages.

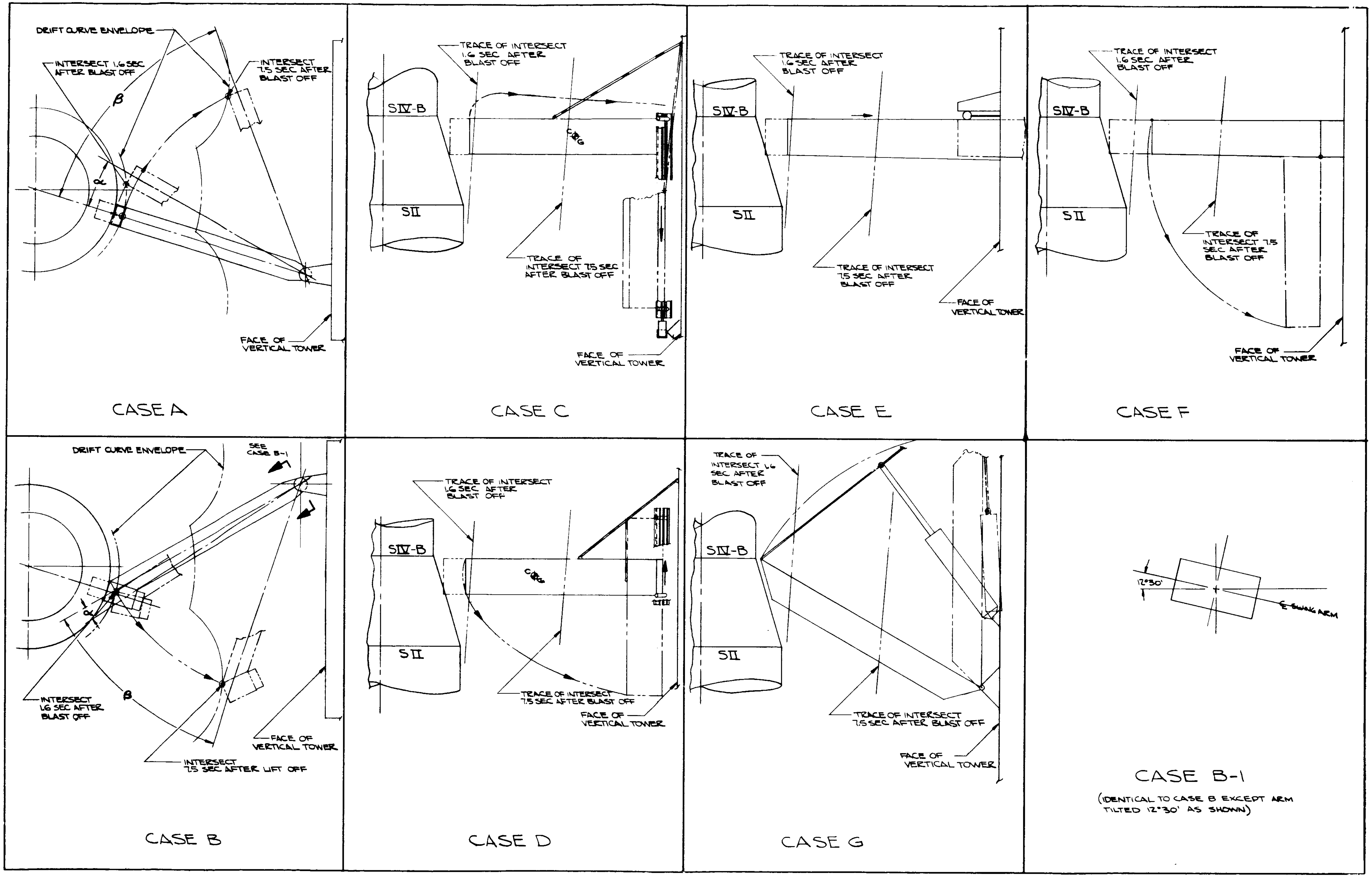

Figure 7-1. Arm Retraction Geometries

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CASE	MOVEMENT TO CLEAR STA 2519	MOVEMENT TO CLEAR DRIFT ANGLE	TIME TO STA 2519	TIME TO DRIFT ANGLE	MOVEMENT PER SEC TO CLEAR STA 2519	MOVEMENT PER SEC TO CLEAR DRIFT ANGLE	OVERALL MOVEMENT PER SEC TO CLEAR DRIFT ANGLE	WEIGHT #	TORQUE REQ'D TO CLEAR STA 2519 ft lbs	TORQUE REQ'D TO CLEAR DRIFT ANGLE ft lbs	MOMENT Ie ft lb SEC²	Id ft lb SEC²
A	12°	69°	1.6 SEC	7.25 SEC	7.437°/SEC	10.1°/SEC	9.53°/SEC	6467	39,440	10,300	120,500	29,676
B	3°	42°	1.6 SEC	7.25 SEC	1.87°/SEC	6.9°/SEC	5.8°/SEC	6787	10,080	6,440	130,100	33,000
C	25°	71°	1.8 SEC	7.8 SEC	13.9°/SEC	7.68°/SEC	9.12°/SEC	6467	64,800	9,830	120,500	30,125
D	24°	68°	1.2 SEC	6.75 SEC	20°/SEC	7.94°/SEC	10°/SEC	6467	131,000	12,590	120,500	30,125
E	70"	245"	1.6 SEC	7.25 SEC	43.65"/SEC	43.4"/SEC	43.5"/SEC	6467	—	—	—	—
F	70"	62°	1.6 SEC	6.75 SEC	43.65"/SEC	12.05°/SEC	—	6467	—	—	—	—
G	14°	45°	1.8 SEC	7.8 SEC	7.78°/SEC	5.17°/SEC	5.77°/SEC	7557	57,000	18,300	189,100	47,275

~~CASE~~	ACCELERATION ~~TO CLEAR~~ STA 2519	ACCELERATION ~~TO CLEAR~~ DRIFT ANGLE	MOMENT ~~Ie WITH 6.5#/ft²~~ WIND DRAG FT LB SEC²	MOMENT ~~Id WITH 6.5#/ft²~~ WIND DRAG FT lb SEC²	TORQUE REQ'D TO CLEAR ~~STA 2519~~ (WITH WIND DRAG)	TORQUE REQ'D TO CLEAR ~~DRIFT ANGLE~~ (WITH WIND DRAG)
A	9.4°/SEC²	2.46°/SEC²	143,100	36,150	48,850	12,230
B	2.34°/SEC²	1.49°/SEC²	169,500	42,470	15,270	8,330
C	15.4°/SEC²	2.44°/SEC²				
D	31.2°/SEC²	2.99°/SEC²				
E	4.56 ft/SEC²	.778 ft/SEC²				
F	4.56 ft/SEC²	1G				
G	8.65°/SEC²	1.48°/SEC²				

Figure 7-2. Comparative Data of Umbilical Arm Retraction Geometries S-IVB Aft Arm

UMBILICAL PLATFORM	VERTICAL MOVEMENT OF VECHICLE TO PLATFORM IMPACT FROM STA 81.277	TIME TO CLEAR DRIFT ANGLE HORIZONTAL MOVEMENT	HORIZONTAL MOVEMENT: TIME TO CLEAR POINT "A" AT STA 2675	TIME TO CLEAR POINT "B" AT STA 2519	TIME TO CLEAR POINT "C" AT STA 1568	TIME TO CLEAR POINT "D" AT STA 874	TIME TO CLEAR POINT "E" AT STA 610
#1	607"	3.6 SEC					
#2	1330"	5.3 SEC					4.1 SEC
#3	1550"	5.7 SEC				4.1 SEC	
#4	2305"	6.88 SEC			4.15 SEC		
#5	2557"	7.30 SEC		1.6 SEC			
#6	3105"	8.1 SEC	3.25 SEC				
#7							
#8							
#9							

UMBILICAL PLATFORM	TIME TO CLEAR DRIFT ANGLE: VERTICAL MOTION ↑	VERTICAL MOTION ↓
#1	4.35 SEC	3.0 SEC
#2	5.0 SEC	4.75 SEC
#3	6.28 SEC	5.25 SEC
#4	7.55 SEC	6.50 SEC
#5	7.8 SEC	6.75 SEC
#6	8.78 SEC	7.5 SEC
#7		
#8		
#9		

REMARKS: ALL DISTANCES AND TIMES MEASURED FROM STA 81.277" AND T-0.

Figure 7-3. Comparative Data of Umbilical Arm Retraction Geometries - All Arms

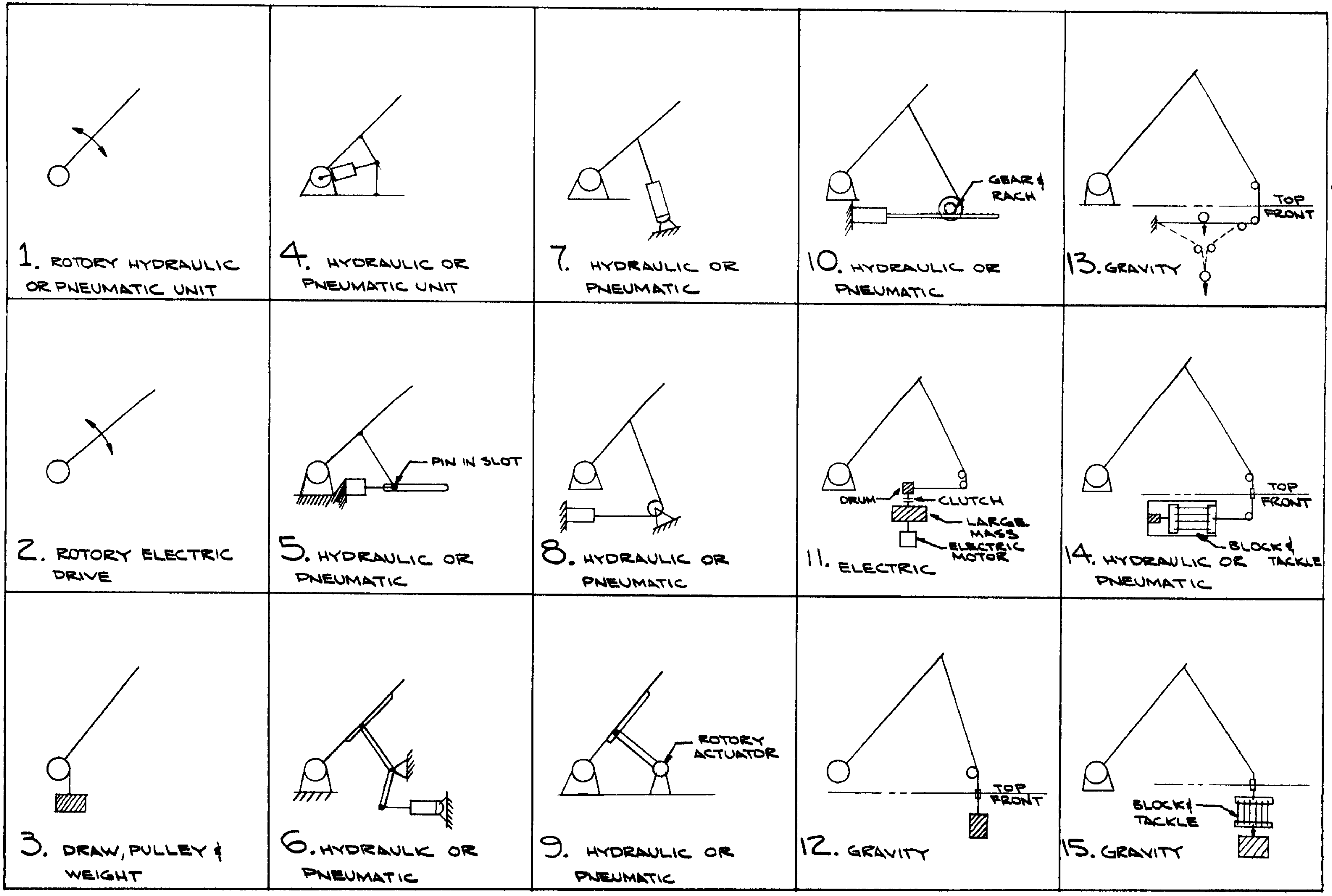

Figure 7-4. Arm Retraction Actuator

ADVANTAGES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Can be used for deceleration also.	x	x		x	x	x	x		x						
2. Hard plumbing can be used for actuator.	x				x			x	x	x				x	
3. Power can come from an accumulator close by.	x			x	x	x	x	x	x	x		x	x	x	x
4. Reflected torque is distributed over a large part of the tower.					x			x		x	x	x	x	x	x
5. High initial (as compared to average) forces can be produced.				x	x	x			x				x		
6. Can be used to swing arm from tower to vehicle.	x	x		x	x	x	x		x						
7. Short stroke on actuator.													x	x	x

(Column heading above the numbered columns: VARIOUS CONFIGURATIONS)

DISADVANTAGES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Cannot be used for deceleration.			x					x		x	x	x	x	x	x
2. Plumbing requires flexible lines.				x		x	x								
3. Power must come from ground level.		x									x				
4. Reflected torque is applied to only a few tower members.	x	x	x	*	*		x		x						
5. Large forces will be required for deceleration.				x	x	x			x						
6. Cannot be used to swing arm from tower to vehicle.			x					x		x	x	x	x	x	x
7. Must have shock absorber to stop arm motion.			x					x		x	x	x	x	x	x
8. Requires large amount of extra space.												x	x		
9. Excessive stroke on actuator.				*	*			*							
10. Low initial acceleration.					*	x			x						

(Column heading above the numbered columns: VARIOUS CONFIGURATIONS)

***Denotes questionable disadvantages that are dependent upon detail design.**

Figure 7-5. Actuator Evaluation

Based on this data, the stage contractors' representatives recommend that a rotary actuator, backed up by a gravity actuated system, be used.

C. BASIC ARM STRUCTURE - SERVICE ARM

1. Proposed Configuration.

There are advantages in using a standard basic arm, adjacent to the tower, with vehicle end-extensions to complete a specific arm.

The arms should be a modular design with a high degree of interchangeability to allow stocking a minimum number of assemblies.

The basic arm length is determined by the cantilever distance between the face of the umbilical tower and the skin of the vehicle at its largest diameter. A clearance of a minimum of 60 inches should be maintained between the skin of the vehicle and the end of the arm structure at all stages. For purposes of illustration, the distance from the centerline of the actuator to the end of the basic arm is 444 inches (figure 7-6),

Basic arm extensions will be used at stages of smaller diameter. They will have the same centerline cross section dimensions as the end of the basic arm. At the present time, the maximum fixed extension length is approximately 68 inches (figure 7-7).

Employment of the same basic structure for all service arms is advantageous for the following reasons:

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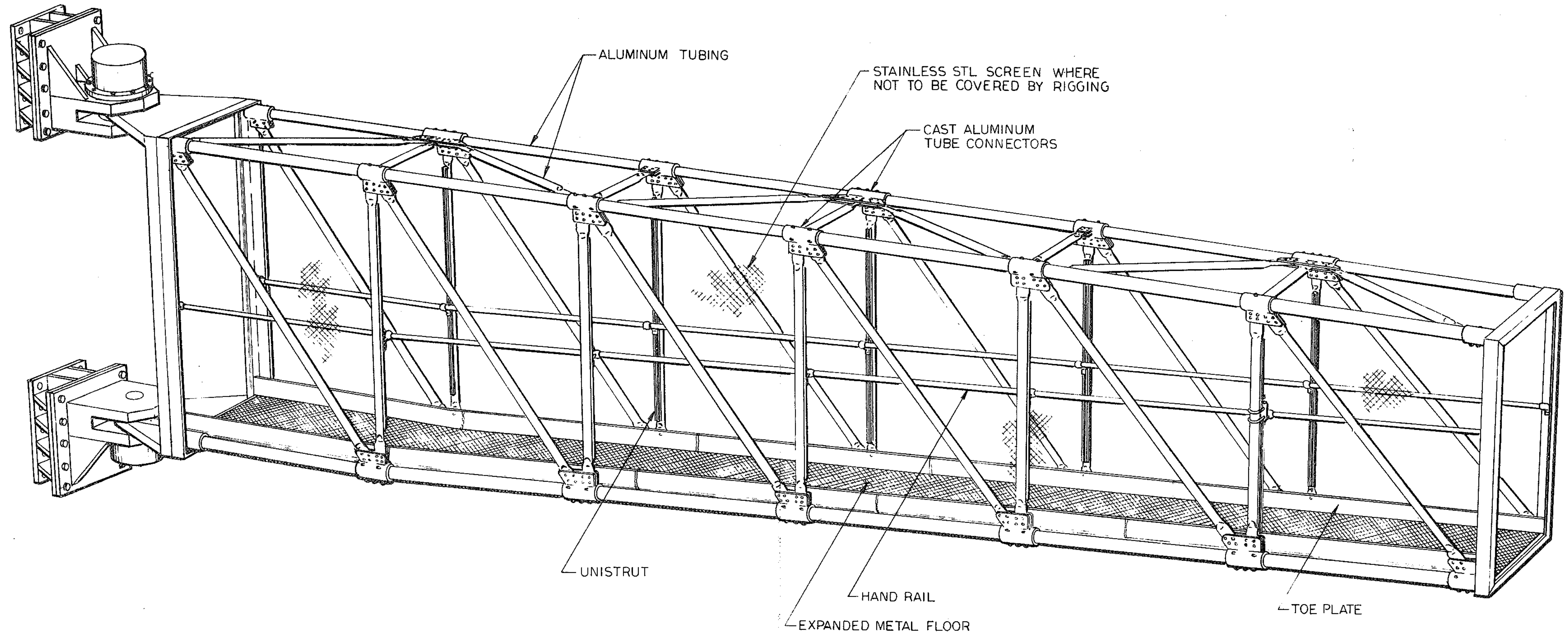

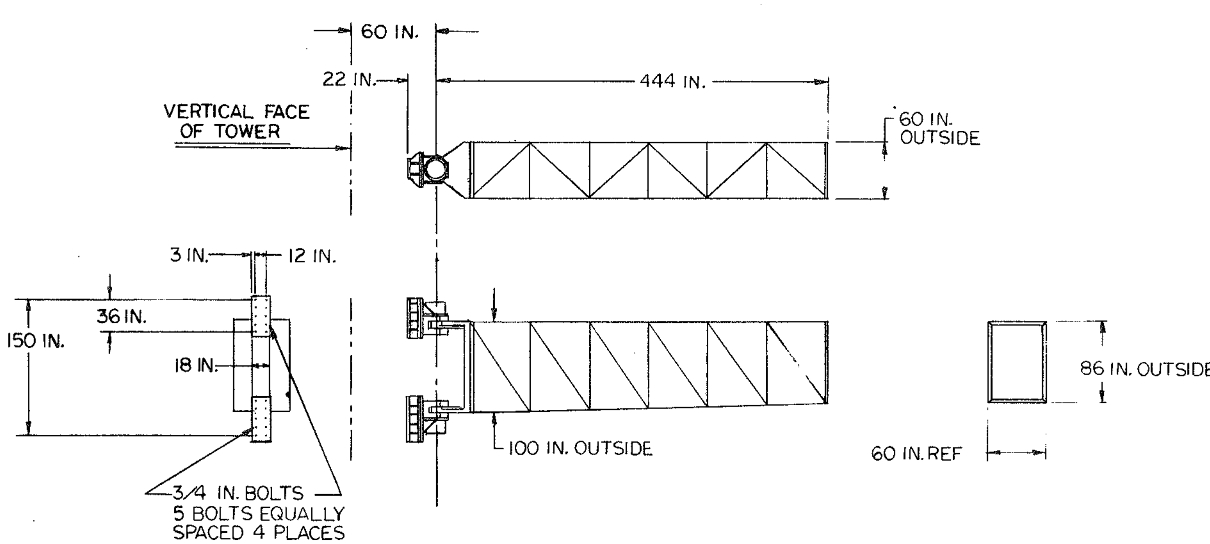

NOTES:
1. THIS BASIC ARM SHOWN WITHOUT EXTENSION PLATFORM.
2. LENGTHS LONGER THAN BASIC ARM ARE OBTAINED WITH ADDED SECTION.

Figure 7-6. Basic Service Arm Structure

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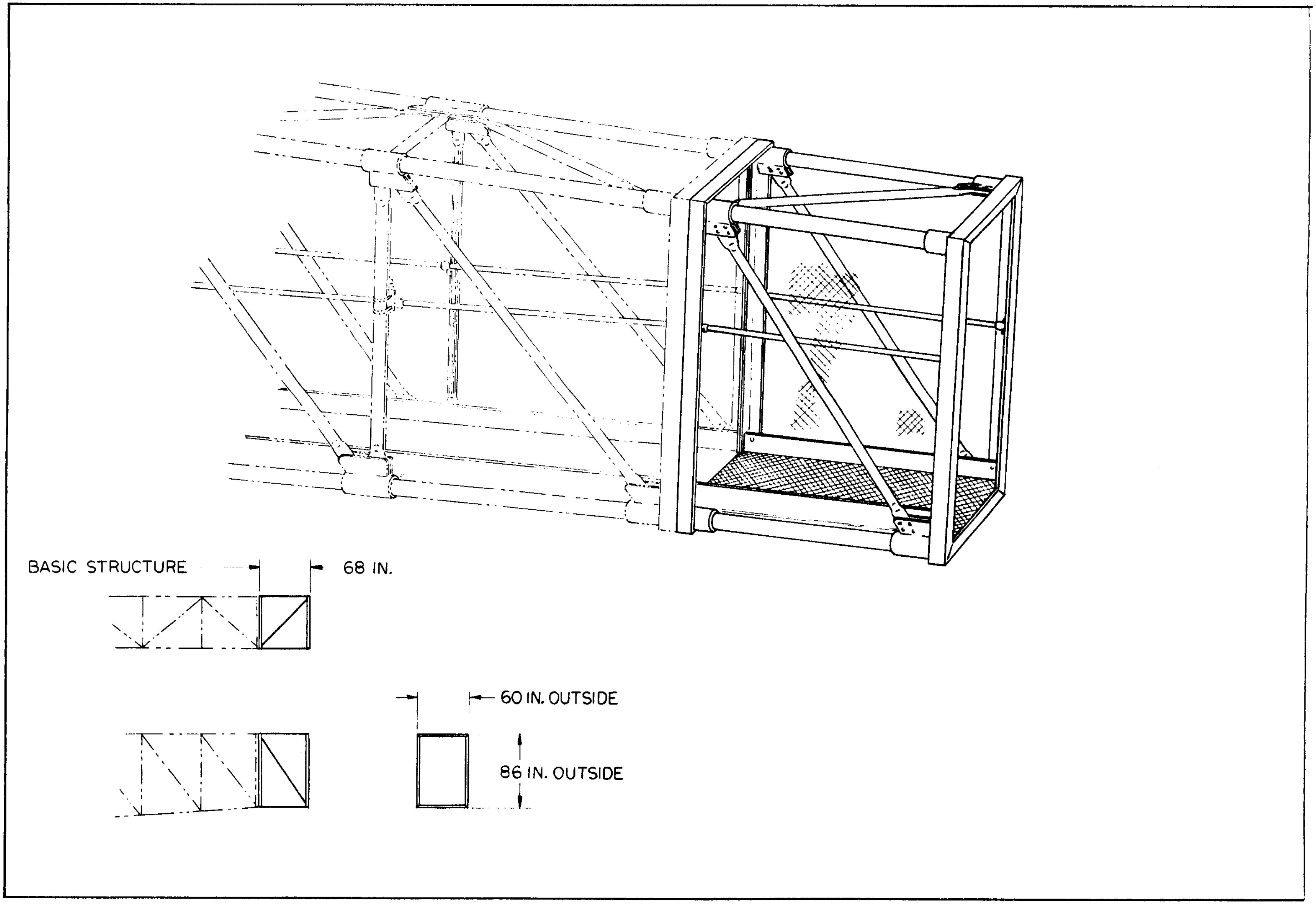

Figure 7-7. Basic Arm Extension

a. Structural cost differential, based on weight, between a heavier and lighter arm is small.

b. This allows the basic arms to be completely interchangeable.

c. Fabrication costs for joints (castings or extrusions) are held to a minimum since there are many similar connections.

d. Assembly line production can be accomplished, resulting in time and labor savings.

e. Effects of the blast on the service arm at launch are not known at this time. It may be assumed that the arm is partially expendable until proven otherwise. Stocking of basic arms would minimize the time required to replace those destroyed at launch.

For personnel safety, it is desirable to have one-inch mesh, stainless-steel wire around the inside of the truss. This would prevent the dropping of tools as well as provide maximum safety for personnel on the arm. Stainless steel is selected because of its heat resistance properties.

The floor of the arm should be of open-type material, but the holes should be small enough to prevent the dropping of tools. This type floor will give minimum resistance to the vehicle blast and allow rain or other liquids to fall through. A rough surface should be provided to prevent slipping. Either expanded-metal flooring or

grating will meet the requirements; but due to the extreme heat at blast-off, the expanded metal would probably be more desirable. If the arm is to be destroyed during launch, the cheaper of the two should be used.

A head clearance of 78 inches and a walkway clear width of 42 inches should be maintained throughout the truss. This would enable a workman to carry a 30-inch cubical package through it with ease.

It is suggested that mounting channel be used on the inside of the truss at each vertical member to secure the umbilical lines. Placing the lines inside the truss would give the workmen easy access to the lines for replacement and maintenance.

2. Arm Loading: Static and Dynamic.

The aft arms for the S-II and S-IVB stages were selected to investigate the loads on the basic truss, because they experience the most severe conditions.

A chart showing the design wind loads at various heights for the C-5 vehicle is shown in Section VI.

Recommended load factors to be used in conjunction with structural design of the service arms and based on the yield point of the material are as follows:

Live Load	6
Dead Load	2
Wind Load	2

The minimum torque required at the actuator is approximately 1,000,000 in.-lb (Appendix B). This torque requirement is based on a noncollision course, with wind being considered. The time element is based on obtaining a full arm retraction before engine exhaust can impose a blast load on the arm structure.

3. Structural Material.

Tentative sizes for the main chords were determined by preliminary calculations made for the tower end of the S-II and S-IVB aft arms. Aluminum was tentatively chosen as the basic structural material because of its light weight. The bottom chord in compression governs the main chord design. When the value of $\frac{KL}{R}$ for a given panel length exceeds the value of C as quoted in the Alcoa Structural Handbook, the choice of alloys becomes optional.

Where: K = Fixity Constant

L = Length of the Member

R = Least Radius of Gyration

C = Constant for Mechanical Properties of the Material

Several alloys within this range were chosen for comparative cost studies. Because of its relatively low cost per pound, good formability,

weldability, corrosion resistance, and strength after heat treatment, 6061-T6 aluminum is recommended for the structural material. This alloy has also been proven in previous umbilical arm structures. Aluminum casting material should have similar characteristics to 6061-T6.

An investigation was made of the possibility of using 0 temper alloy because of the blast temperatures involved. This would require a larger tube, which is impractical for the situation, both structurally and from a cost standpoint.

4. Structural Material Properties, Design Data and Allowables.

In investigating the S-II and the S-IVB aft arms, it was found that the S-II arm requires the larger truss members. A tentative size for the main chords of the S-II arm was determined to be a 3 inch OD tube with 7/16 inch wall, compared to a 3-inch OD tube with a 1/4 inch wall for the S-IVB arm and all other arms of the C-5 vehicle. Bracing between chord members of the S-II arm requires approximately a 2-1/2 inch OD tube with a 3/16 inch wall for tension members and a 3 inch OD tube with a 5/16 inch wall for compression members. The S-IVB arm requires approximately a 2-1/2 inch OD tube with a 3/16 inch wall for tension members and a 3 inch OD tube with a 1/4 inch wall for compression members. Because of the nearness in size of these tubes, and the advantages of uniform

construction, it is suggested that all the basic trusses be made to meet the requirement of the S-II arm.

Extensions for the upper arms can be made entirely of 2-1/2 inch OD tubing with a 3/16 inch wall. This is based on the specification of a maximum $\frac{L}{R}$ of 150 for tension members.

5. Arm Characteristics.

Preliminary calculations for a fully loaded, S-II aft arm show that there will be a live load deflection of about 1-3/4 inches at the end of the service arm if the 3-inch OD tube with a 7/16 inch wall is used for the main chords. The mass moments of inertia are computed to be 3,160,000in.-lb-secs^2 for the S-II aft arm, and 2,070,000 in.-lb-secs^2 for the S-IVB aft arm. The solidity ratio was figured at about 56 percent; therefore, a drag coefficient of 60 percent was used in the wind calculations.

D. SERVICE ARM EXTENSION PLATFORM

The design criteria for the service arm extension platforms are as follows:

1. The platform must be able to track the vehicle during total wind load displacements in any horizontal direction.

2. Close coordination with stage design will be necessary for any loads the platform may impart on the vehicle.

3. The platform must provide a stable work area for one to

three persons and their tools and equipment. Internal clearance shall be no less than 42 inches in width and 78 inches in height.

4. Maximum personnel safety is required.

5. The platform must provide access to the access hatches and umbilical areas.

6. The platform must have only one manual positioning station from which connection to the vehicle can be established with no remote control capability.

7. The platform must have a positive lock in the retracted position.

Three types of platforms are considered in this study.

Figure 7-8 is a telescoping segment platform incorporating a rigid base section. The entire platform rotates about the base section pivot point under the influence of differential tension in the retraction cables. At the same time, the third telescoping section counter-rotates about its own pivot point to maintain a working area perpendicular to the vehicle. Counter-rotation of the third section is achieved by crossing the tension cables beneath the third section. A pneumatic bumper prevents actual contact of the vehicle and the platform.

The primary advantage of the platform is its structural simplicity and low mass. The primary disadvantage is the lack of personnel safety, due to the flexible sides.

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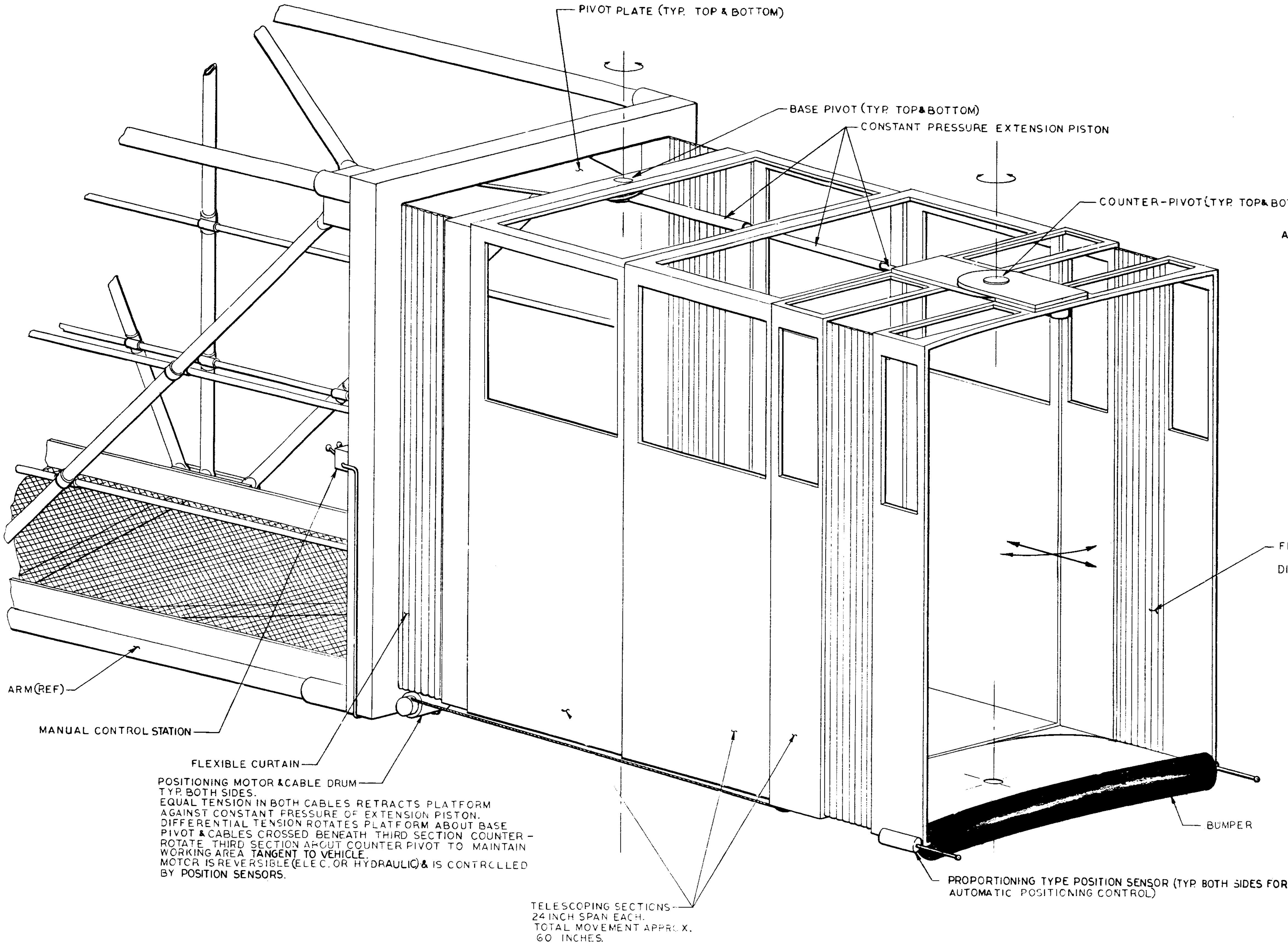

ADVANTAGES:

1. PROVIDES AREA AT ARM TIP WHICH CLOSELY FOLLOWS VEHICLE MOTION.
2. HAS CAPABILITY OF BEING CONNECTED TO VEHICLE (FOR MOTION FOLLOW) AS ALTERNATE TO CONTINUOUS SERVO OPERATION.
3. ONLY A SMALL PRESSURE AGAINST VEHICLE WITH SERVO POSITIONING.
4. CONVEYS SECURE FEELING BY ENCLOSED PROTECTION AT ARM TIP.

DISADVANTAGES:

1. REQUIRES POWER AND SERVOMECHANISMS UNLESS PINNED TO VEHICLE.
2. TELESCOPING SECTIONS REQUIRE ADDITIONAL DISTANCE BETWEEN BASIC ARM TIP AND VEHICLE SKIN FOR STACKING SPACE.
3. MANY SLIDING JOINTS HAVE NEED FOR PROTECTION OF TOE AND HAND CRUSHING.
4. HIGH FRICTION FORCES.
5. FAILURE OF SERVOMECHANISMS TO FOLLOW VEHICLE, OR JAMMING, MAY RESULT IN LARGE FORCES APPLIED TO VEHICLE SKIN.
6. FAILURE OF SERVOMECHANISM AS PERSONNEL STEPS FROM ACCESS DOOR COULD RESULT IN PLATFORM PULLING AWAY.
7. FLAT SURFACES HAVE POOR ACOUSTIC AND BLAST SURVIVAL.
8. NOT WIDE ENOUGH TO COVER OUTBOARD DISCONNECT ON S-IVB AND S-II STAGES.
9. NOT HIGH ENOUGH FOR S-II AND S-IVB STAGES TO COVER DISCONNECT AND ACCESS DOOR.

Figure 7-8. Service Arm Extension Platform Telescoping

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Figure 7-9 is an open construction, multiple section platform, consisting of a rotatable section to provide approximately 20 degrees of movement to either side of the centerline, an extension section, and a counter-rotation table. All sections are mounted on low friction rollers. Rotation is about the forward end of the rotation section to keep the mass moment of inertia as low as possible. Platform side-protection is provided by reel-wound, flexible curtains, which extend and contract with the platform. The drums could have inertia locks to protect personnel against falling. Handrails on the outer sections are removable to facilitate full retraction.

The primary advantage of the platform is its minimum of protrusions to the sides and rear of the service arm, allowing maximum use of attachments for other systems. The primary disadvantages are the structural complexity, high mass and consequent high inertias.

Figure 7-10 shows a T-shaped extension platform in which the floor section nearest the vehicle and hand rails on this section will follow the vehicle's east-west motion by a servo follow-up on the bottom of the section. The whole extension platform would follow the vehicle as shown in the figure. Where necessary, the section of the platform nearest the vehicle could be elevated by a scissors-type jack, with the base of the jack still following the vehicle's motion.

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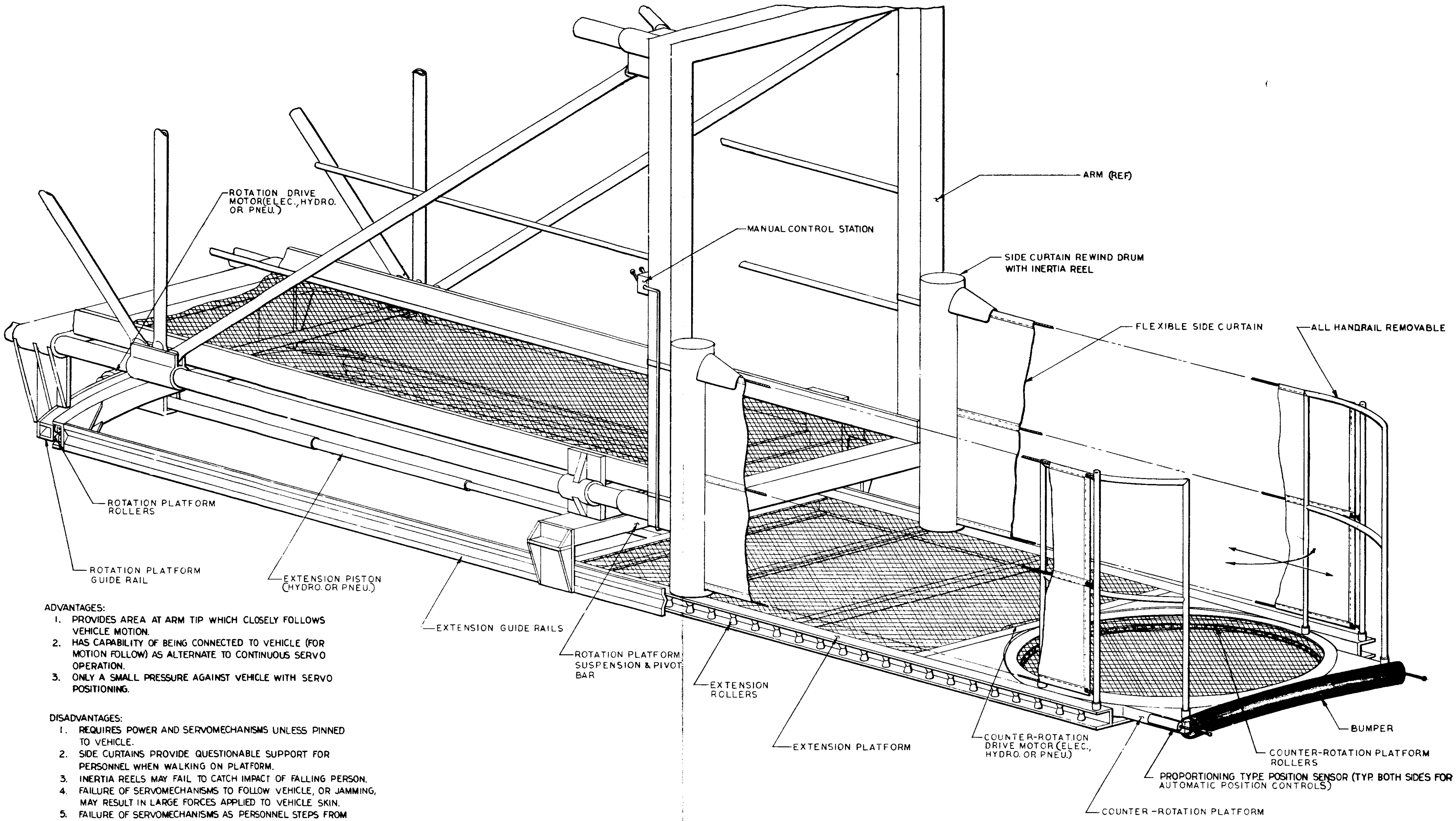

ADVANTAGES:

1. PROVIDES AREA AT ARM TIP WHICH CLOSELY FOLLOWS VEHICLE MOTION.
2. HAS CAPABILITY OF BEING CONNECTED TO VEHICLE (FOR MOTION FOLLOW) AS ALTERNATE TO CONTINUOUS SERVO OPERATION.
3. ONLY A SMALL PRESSURE AGAINST VEHICLE WITH SERVO POSITIONING.

DISADVANTAGES:

1. REQUIRES POWER AND SERVOMECHANISMS UNLESS PINNED TO VEHICLE.
2. SIDE CURTAINS PROVIDE QUESTIONABLE SUPPORT FOR PERSONNEL WHEN WALKING ON PLATFORM.
3. INERTIA REELS MAY FAIL TO CATCH IMPACT OF FALLING PERSON.
4. FAILURE OF SERVOMECHANISMS TO FOLLOW VEHICLE, OR JAMMING, MAY RESULT IN LARGE FORCES APPLIED TO VEHICLE SKIN.
5. FAILURE OF SERVOMECHANISMS AS PERSONNEL STEPS FROM ACCESS DOOR TO PLATFORM COULD RESULT IN PLATFORM PULLING AWAY.
6. NOT WIDE ENOUGH TO COVER OUTBOARD DISCONNECT ON S-IVB AND S-II STAGES.
7. NOT HIGH ENOUGH FOR S-II AND S-IVB STAGES TO COVER DISCONNECT AND ACCESS DOOR.

Figure 7-9. Service Arm Extension Platform Rotatable

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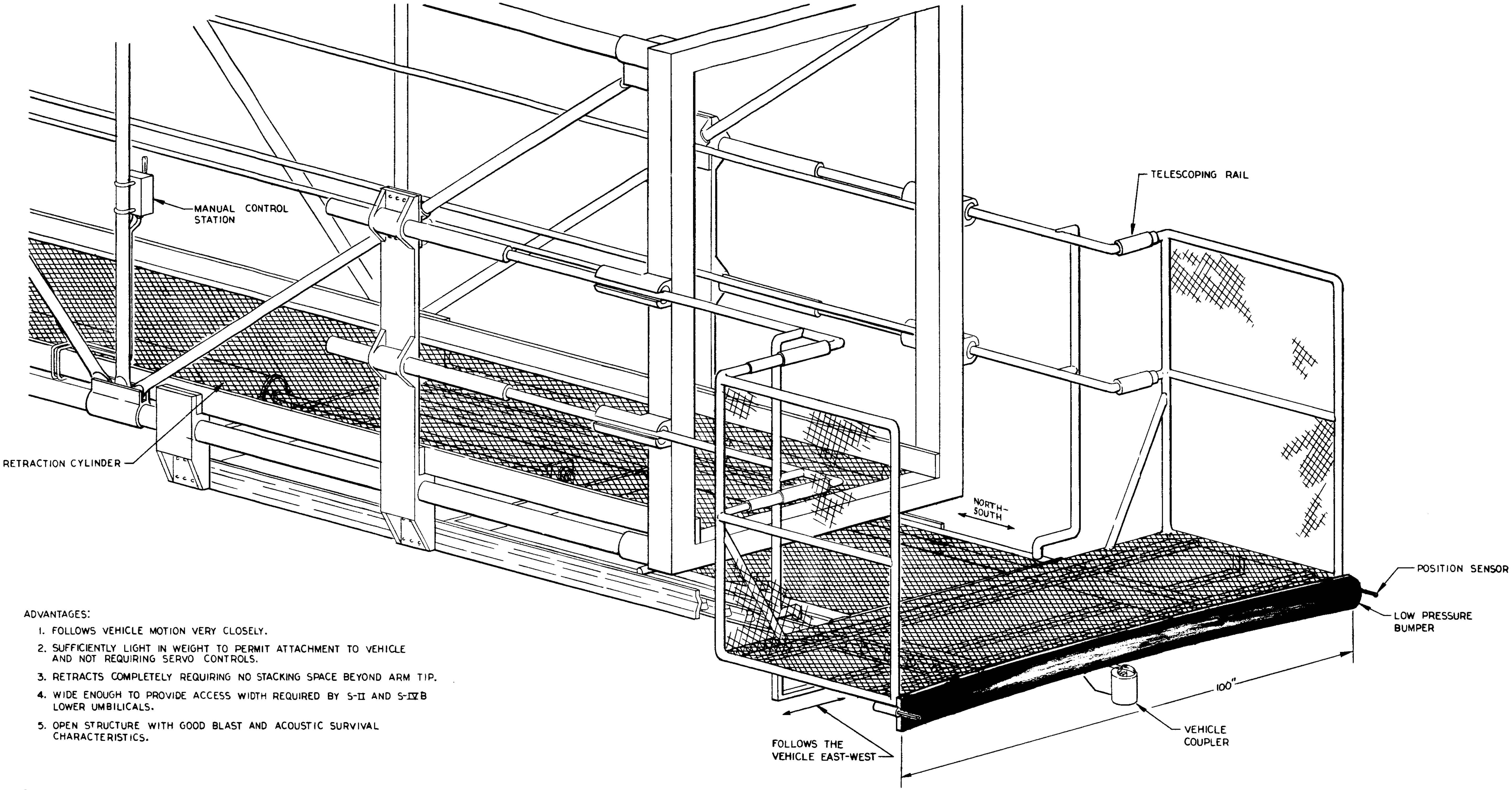

ADVANTAGES:

1. FOLLOWS VEHICLE MOTION VERY CLOSELY.
2. SUFFICIENTLY LIGHT IN WEIGHT TO PERMIT ATTACHMENT TO VEHICLE AND NOT REQUIRING SERVO CONTROLS.
3. RETRACTS COMPLETELY REQUIRING NO STACKING SPACE BEYOND ARM TIP.
4. WIDE ENOUGH TO PROVIDE ACCESS WIDTH REQUIRED BY S-II AND S-IVB LOWER UMBILICALS.
5. OPEN STRUCTURE WITH GOOD BLAST AND ACOUSTIC SURVIVAL CHARACTERISTICS.

DISADVANTAGES:

1. UNABLE TO SCREEN ALL SIDES FOR PERSONNEL SECURITY.
2. LIMITATIONS IMPOSED ON RETRACTED ARM PROTRUSION FROM TOWER.

Figure 7-10. Service Arm Extension Platform T Shaped

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The primary advantages of the T-shaped extension will permit access to the vehicle, impose minimum loads to the service arm, and provide access to the disconnect area wherever necessary.

E. DISCONNECT AND RECONNECT MECHANISMS

The umbilical disconnect mechanism is the mechanical apparatus which disengages the ground half of the umbilical plate, and withdraws it from the vehicle. This apparatus is located at the end of each service arm. Primary disengagement and withdrawal may be accomplished either hydraulically, pneumatically or electrically. Primary disengagement and withdrawal would preferably be completed just before retraction of the service arm.

There are currently three philosophies regarding umbilical plate separation.

1. Preflight disconnect and confirm.
2. Preflight disconnect and confirm with reconnect capability.
3. Post-flight or flyaway (lift-off) disconnect.

The ground rules as originally stated by NASA have tentatively been changed so that release of all umbilical arms except the S-II and S-IVB aft service arms is to be made prior to lift-off. These arms would be lift-off disconnects. The actual decision on release time and affected arms will be made following completion of studies on vehicle penalties. For the present, disconnect mechanisms should

be so designed that they do not prevent the use of either disconnect philosophy.

Reconnect capability is being considered and may be required by NASA. Preflight disconnect would improve launch reliability; consequently, disconnect mechanisms should be of such design that they can be reasonably adapted to include reconnect capability or replaced by reconnect mechanisms entirely. The basic ground rules for design of disconnect mechanisms are as follows:

1. Ground half connection of the umbilical plate will be mated to the vehicle and the disconnect mechanism positioned in the VAB.

2. The disconnect mechanism must track the vehicle throughout all the relative motions between tower and vehicle; that is, through all vertical and horizontal displacements during preflight operations.

3. The mechanism should, preferably, disengage the umbilical plate from the vehicle along a radial center line and normal to the vehicle.

4. In the withdrawn position, the umbilical plate and rigging mechanism must not project beyond the end of the service arm, with reference to the drift envelop.

5. The mechanism must hold the umbilical plate snugly in a withdrawn position, against the acceleration forces due to umbilical arm retraction.

6. The mechanism should not damage the umbilical arm or rigging in coming to a stop after umbilical withdrawal.

7. The mechanism should have a secondary or back-up disengagement capability.

8. Coordination with vehicle design should be made for any loads transferred into the vehicle by this mechanism.

The basic requirements for reconnect capability are as follows:

1. Chase and/or indexing for locating the connection must be accomplished after receipt of a signal.

2. The mechanism would produce proper alignment and reengagement.

3. The mechanism would secure the connection by locking it to the vehicle.

Several studies have been made for disconnect mechanisms and are shown in figures 7-11 through 7-15.

F. UMBILICAL ARM ACTUATOR UNITS

Four principle types of rotation mechanisms were considered in this study: the internal-vane type, rotary actuator unit, similar to the units previously employed with C-1 vehicles; the internal-vane type, pancake, rotary actuator unit; the piston-powered, rack and pinion gear unit; and the piston-powered, lever arm unit. Three systems are shown in figure 7-16. A pancake-mounted actuator is shown in figure 7-6.

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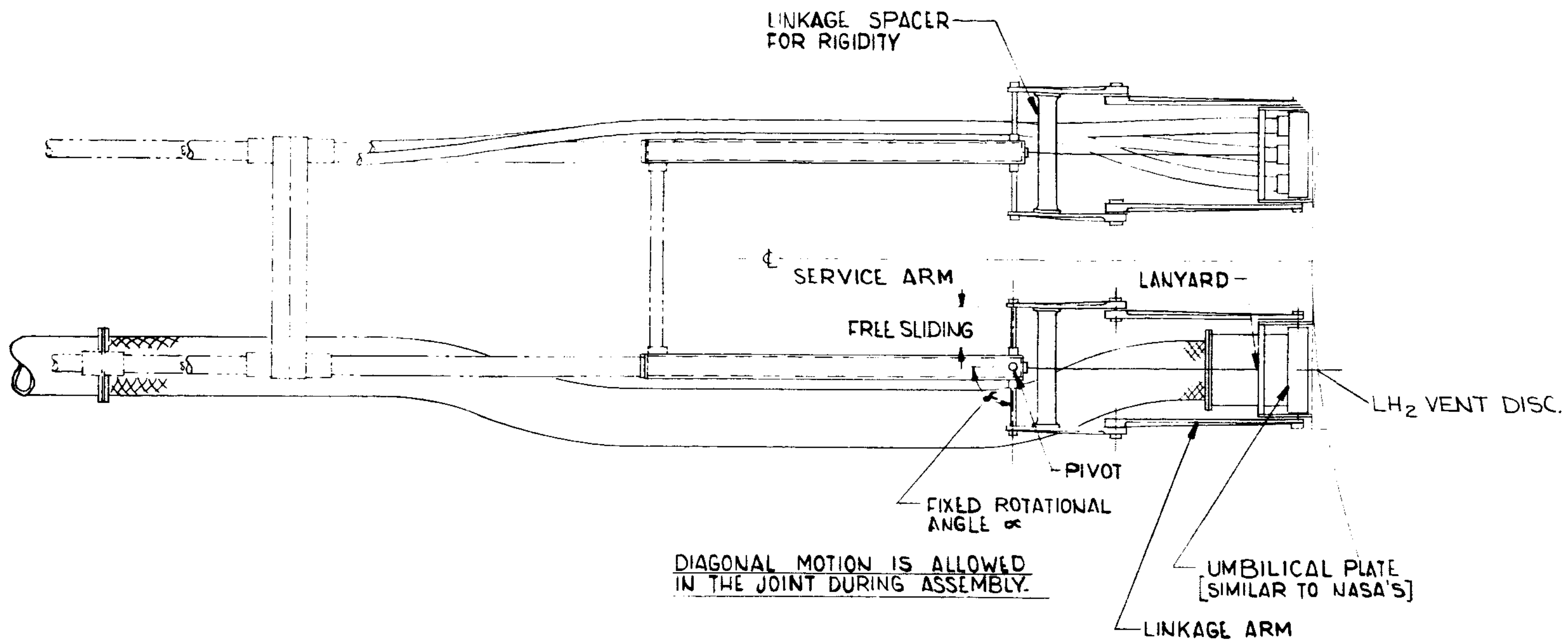

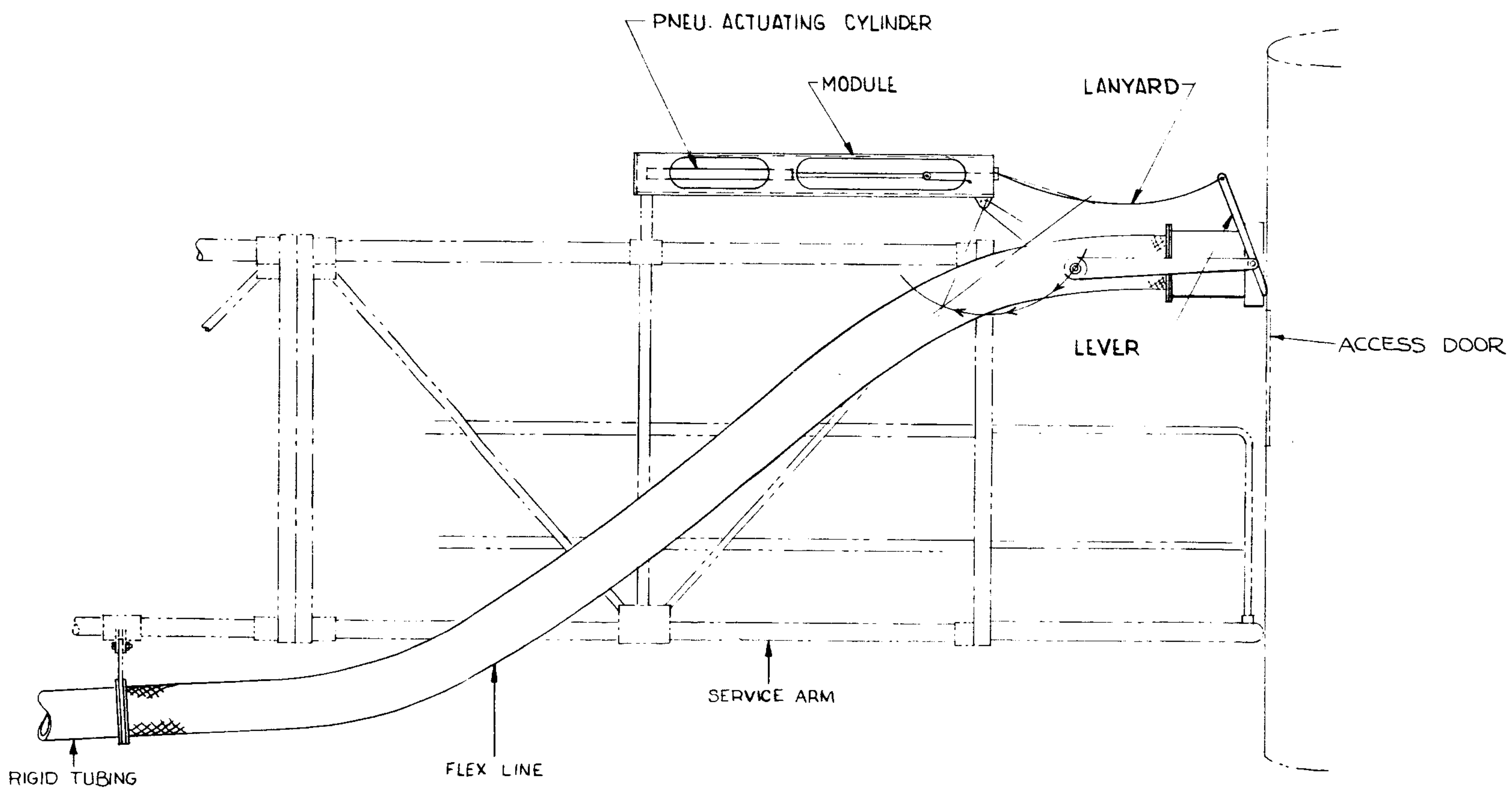

Figure 7-11. Disconnect Mechanism Number One

OPERATION SEQUENCE

WHEN DISCONNECT COMMAND IS RECEIVED BY THE ACTUATING SYSTEM, PNEUMATIC PUSH-OFF PISTON SEPARATES THE UMBILICAL PLATE ASSEMBLY FROM THE VEHICLE. THE PNEUMATIC LANYARD ACTUATING CYLINDER IS ENERGIZED SIMULTANEOUSLY CAUSING THE LANYARD CABLE TO TRIP A BALL-LOCK TYPE RELEASE IN THE UMBILICAL PLATE ASSEMBLY, THUS WITH DRAWING IT BACK TO THE MODULE JUST PRIOR TO THE SERVICE ARM MOTION.

THE LINKAGE ARM ACTS AS A GUIDE DURING SEPARATION OF UMBILICAL PLATE ASSEMBLY AND ALSO PREVENTS IT FROM BOUNCING AROUND DURING SERVICE ARM RETRACTION. THE LINKAGE ARM AND LANYARD CABLE SET-UP PERMITS THE HYDROGEN VENT LINE TO TAKE A NATURAL BEND DURING RETRACT.

ALL MOVEMENT BETWEEN THE VEHICLE AND SERVICE ARM IS TAKEN CARE OF BY ALLOWING ROTATION, PLUS HORIZONTAL AND DIAGONAL MOTION AT THE PIVOT.

ALL THE MODULES AND LINKAGE ARM ARE IDENTICAL FOR EACH SERVICE ARM.

TO MANUFACTURE THIS DISCONNECT SYSTEM WOULD BE VERY SIMPLE SINCE ALL COMPONENTS CAN BE FABRICATED BY STANDARD SHOP METHOD. ACTUATING CYLINDER, BOLTS, CABLE, ARE ALL STANDARD ITEMS.

THE UMBILICAL PLATE WOULD BE SIMILAR TO THE ONES THAT NASA HAS BUILT AND TESTED WITH SUCCESS.

ALTHOUGH THE VENT LINE NORMALLY HANDLES ONLY GASEOUS HYDROGEN, IT IS TO BE SLOPED DOWNWARD FOR DRAINAGE OF LIQUID IN EVENT OF OVERFILLING, BOILOVER, OR SPLASHING.

THIS ARM IS NOT REQUIRED TO HAVE RECONNECT CAPABILITY AS IT PERFORMS A LIFTOFF DISCONNECT FUNCTION ONLY.

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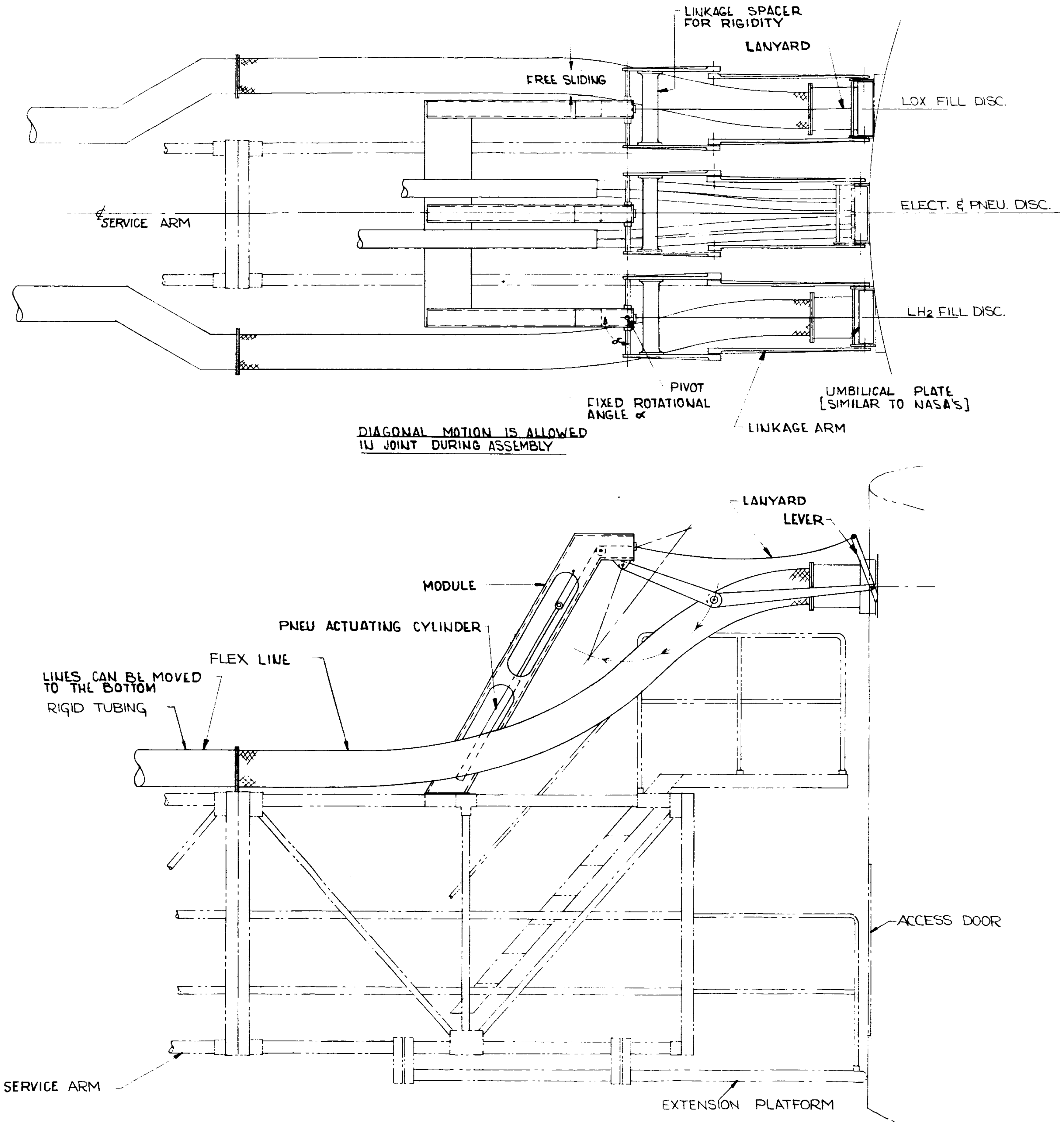

Figure 7-12. Disconnect Mechanism Number Two

OPERATION SEQUENCE

WHEN DISCONNECT SIGNAL IS RECEIVED BY THE ACTUATING SYSTEM, THE PNEUMATIC PUSH-OFF PISTONS SEPARATE THE UMBILICAL PLATE ASSEMBLY FROM THE VEHICLE. THE PNEUMATIC LANYARD ACTUATING CYLINDER IS ENERGIZED SIMULTANEOUSLY CAUSING THE LANYARD CABLE TO TRIP A BALL-LOCK TYPE RELEASE IN THE UMBILICAL PLATE ASSEMBLY AND THUS WITHDRAWING IT BACK TO THE MODULE JUST PRIOR TO THE SERVICE ARM MOTION.

THE LINKAGE ARM ACTS AS A GUIDE DURING SEPARATION OF UMBILICAL PLATE ASSEMBLY AND ALSO PREVENTS IT FROM BOUNCING AROUND DURING SERVICE ARM RETRACTION.

THE LINKAGE ARM AND LANYARD CABLE SET-UP PERMITS THE HYDROGEN FILL LINES TO TAKE A NATURAL BEND DURING RETRACT.

ALL MOVEMENT BETWEEN THE VEHICLE AND SERVICE ARM IS TAKEN CARE OF BY ALLOWING ROTATION, HORIZONTAL AND DIAGONAL MOTION AT THE PIVOT.

ALL THE MODULES AND LINKAGE ARM ARE IDENTICAL FOR EACH SERVICE ARM.

TO MANUFACTURE THIS DISCONNECT SYSTEM WOULD BE VERY SIMPLE SINCE ALL COMPONENTS CAN BE FABRICATED BY STANDARD SHOP METHOD. ACTUATING CYLINDER, BOLTS, CABLES, ARE ALL STANDARD ITEMS.

THE UMBILICAL PLATE WOULD BE SIMILAR TO THE ONES THAT NASA HAS BUILT AND TESTED WITH SUCCESS.

THIS ARRANGEMENT DOES NOT HAVE REMOTE RECONNECT CAPABILITY FOR PROPELLANT LOADING LINES.

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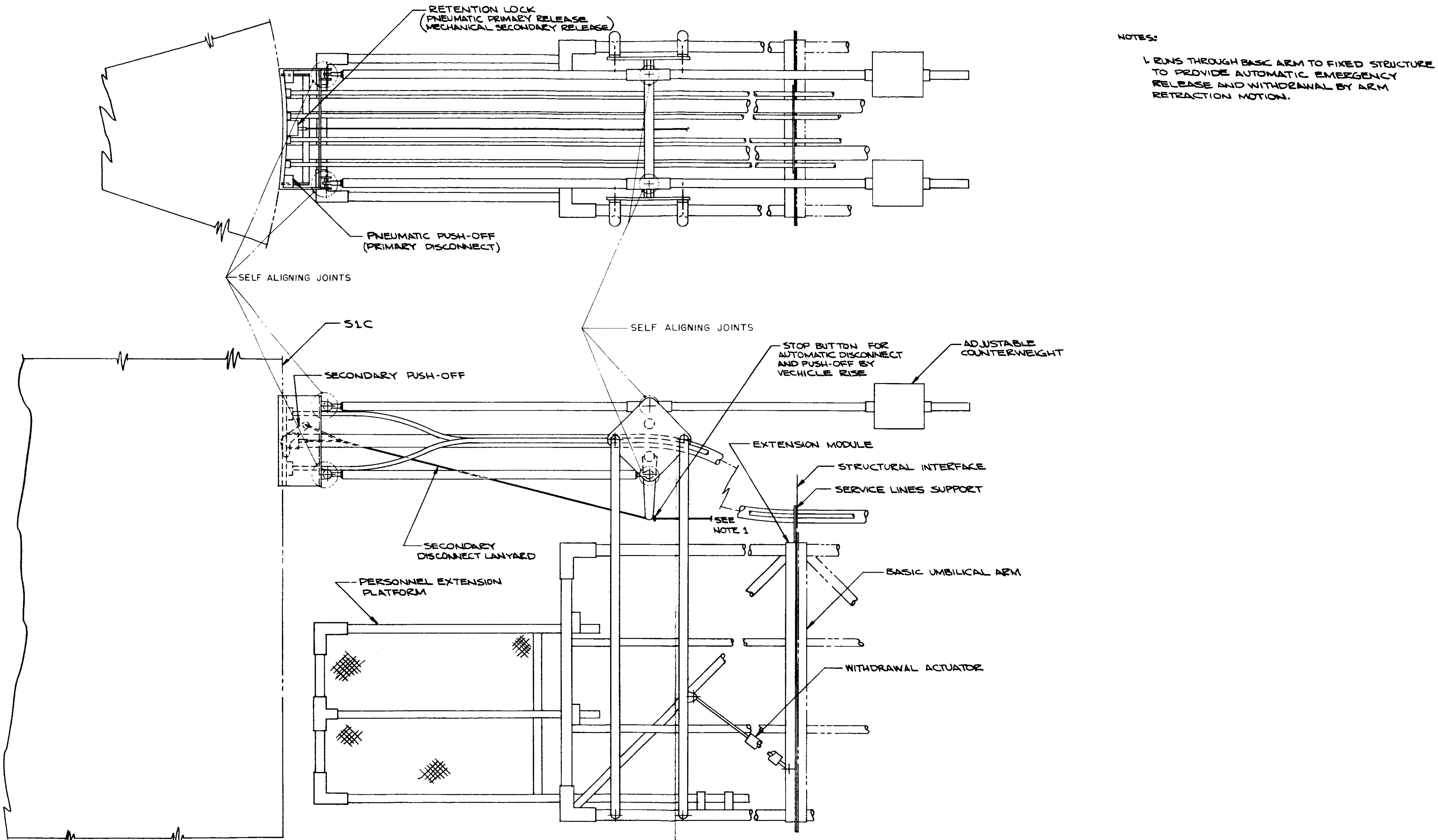

Figure 7-13. Disconnect Mechanism Number Three

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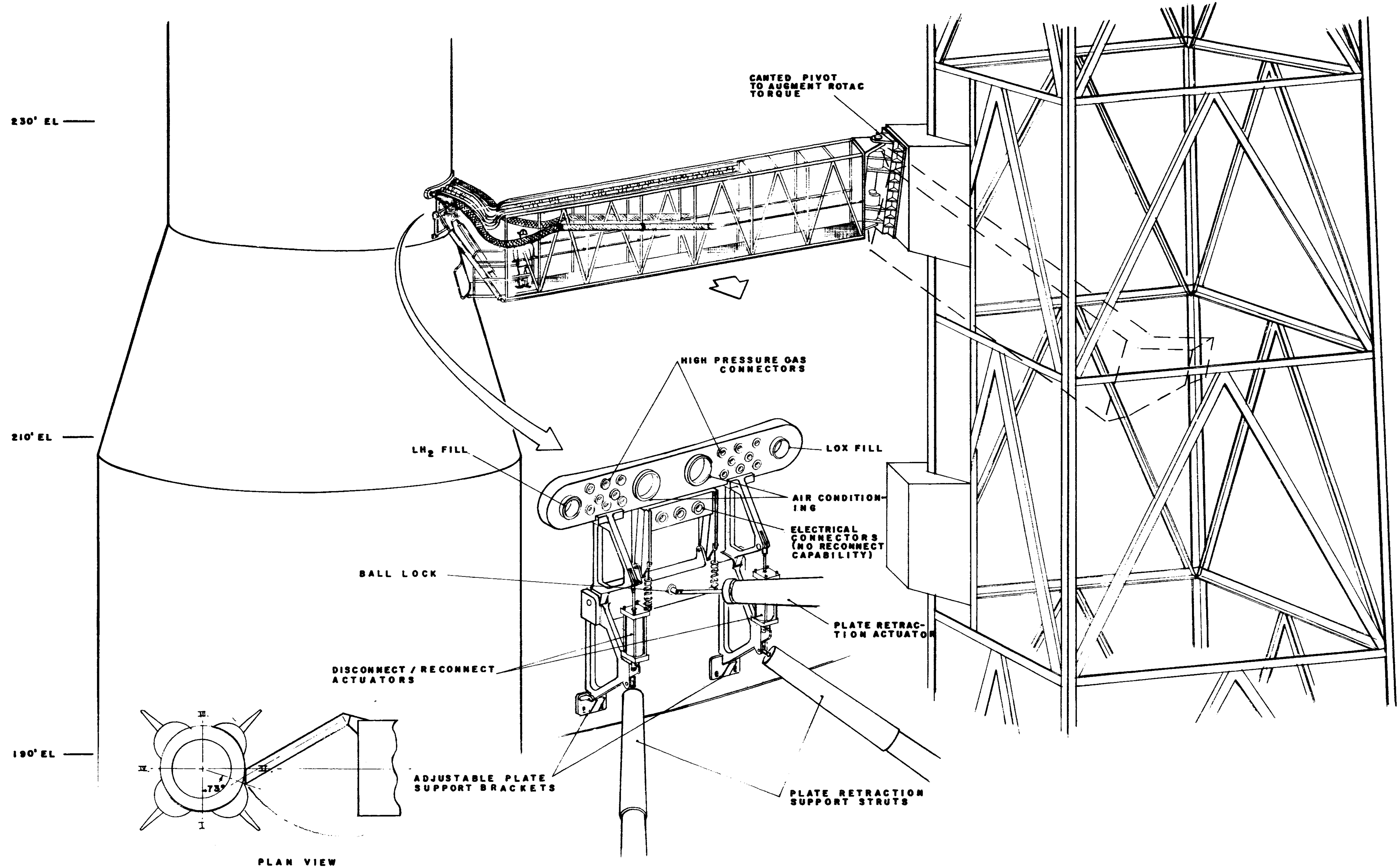

Figure 7-14. Disconnect Mechanism Number Four

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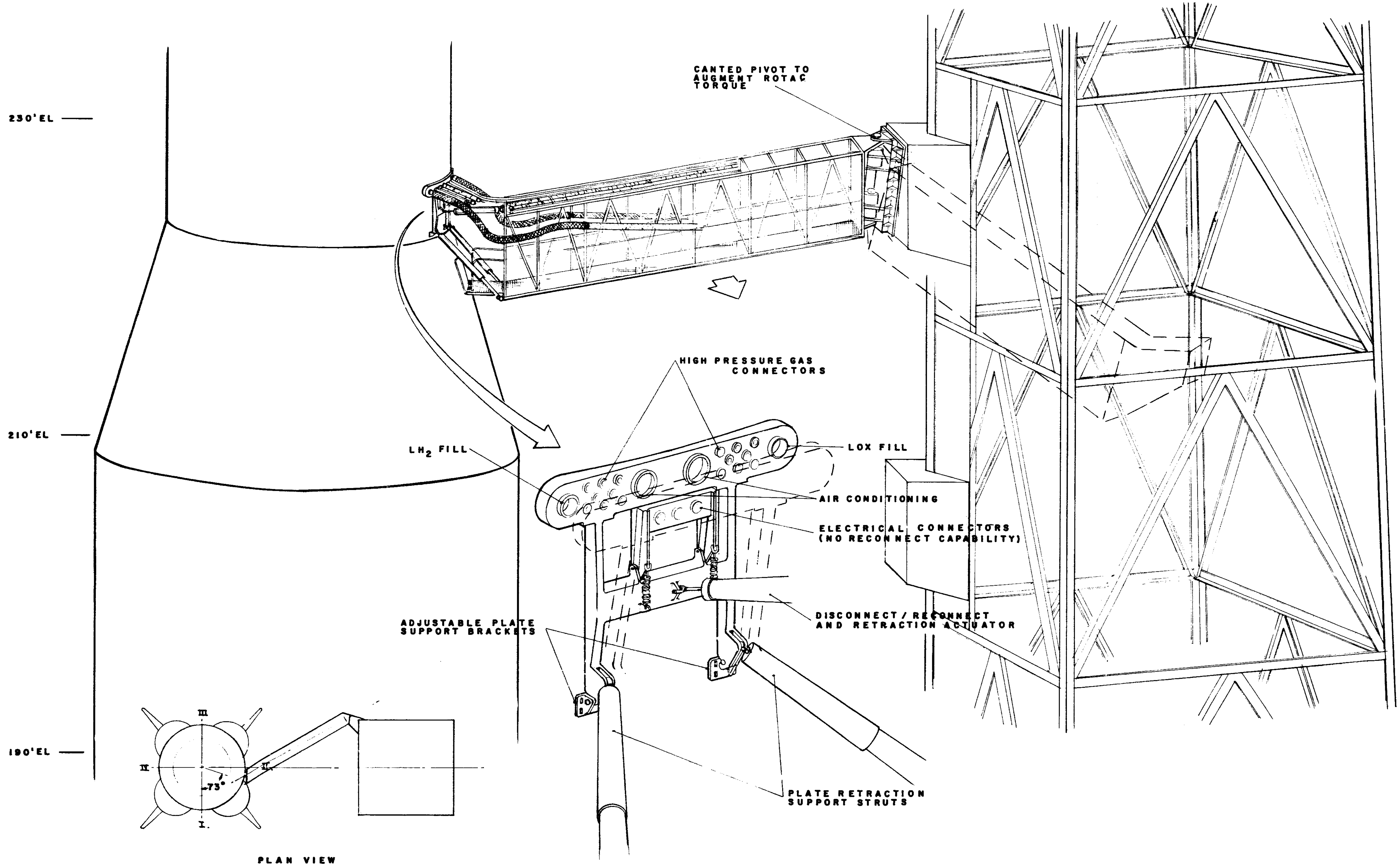

Figure 7-15. Disconnect Mechanism Number Five

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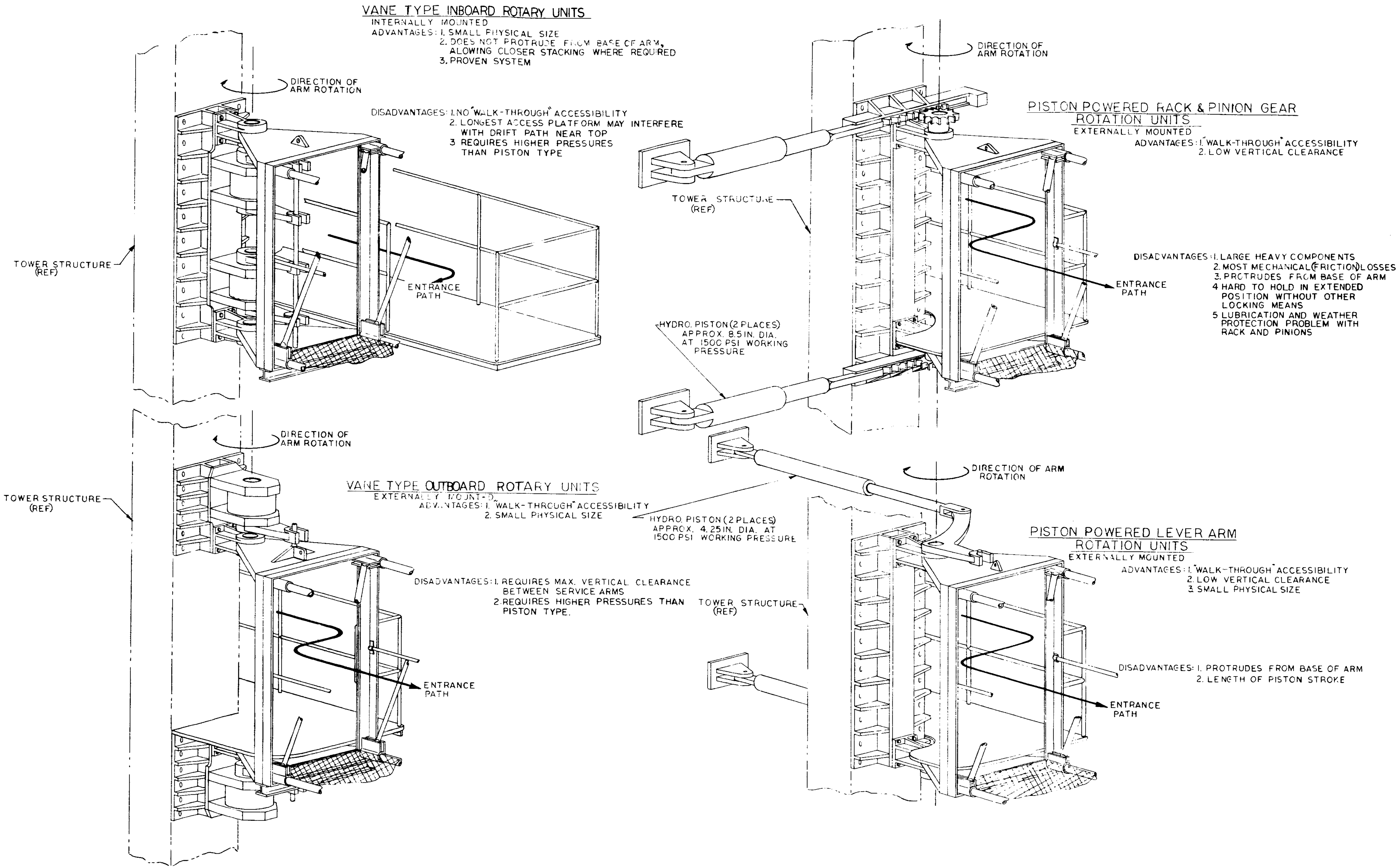

Figure 7-16. Actuator Units

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All units are hydraulically powered. The major advantages and disadvantages of each unit are also shown in the figure.

G. BUMPER-LATCH-BACK ASSEMBLIES

Two bumper-latch-back assemblies (figure 7-17) would be installed for each umbilical arm. A long single-bumper, latch-back unit was not used because of possible interference with the umbilical disconnect mechanism or with umbilical lines along the outside of the arms. The assemblies would provide both a rigid stop and a positive locking mechanism for holding the umbilical arms in their retracted positions during launch. The bumper-latch-back assemblies will be located as near the vehicle end of the arms as possible. The upper assembly will be positioned opposite the top chord and will be attached to a vertical mounting beam on the umbilical tower. The lower assembly will be positioned opposite the bottom chord and may be attached to either the auxiliary arm support as shown in figure 7-17, section A-A, or to the tower's vertical mounting beam. The bumper will have a shock absorber to prevent damage to the umbilical arms. An alternate section (D-D) in this same figure, depicts installation of hydraulic shock absorbers for the umbilical arms. These shock absorbers are required to decrease the kinetic energy of the arms which might be produced by an accelerating wind load.

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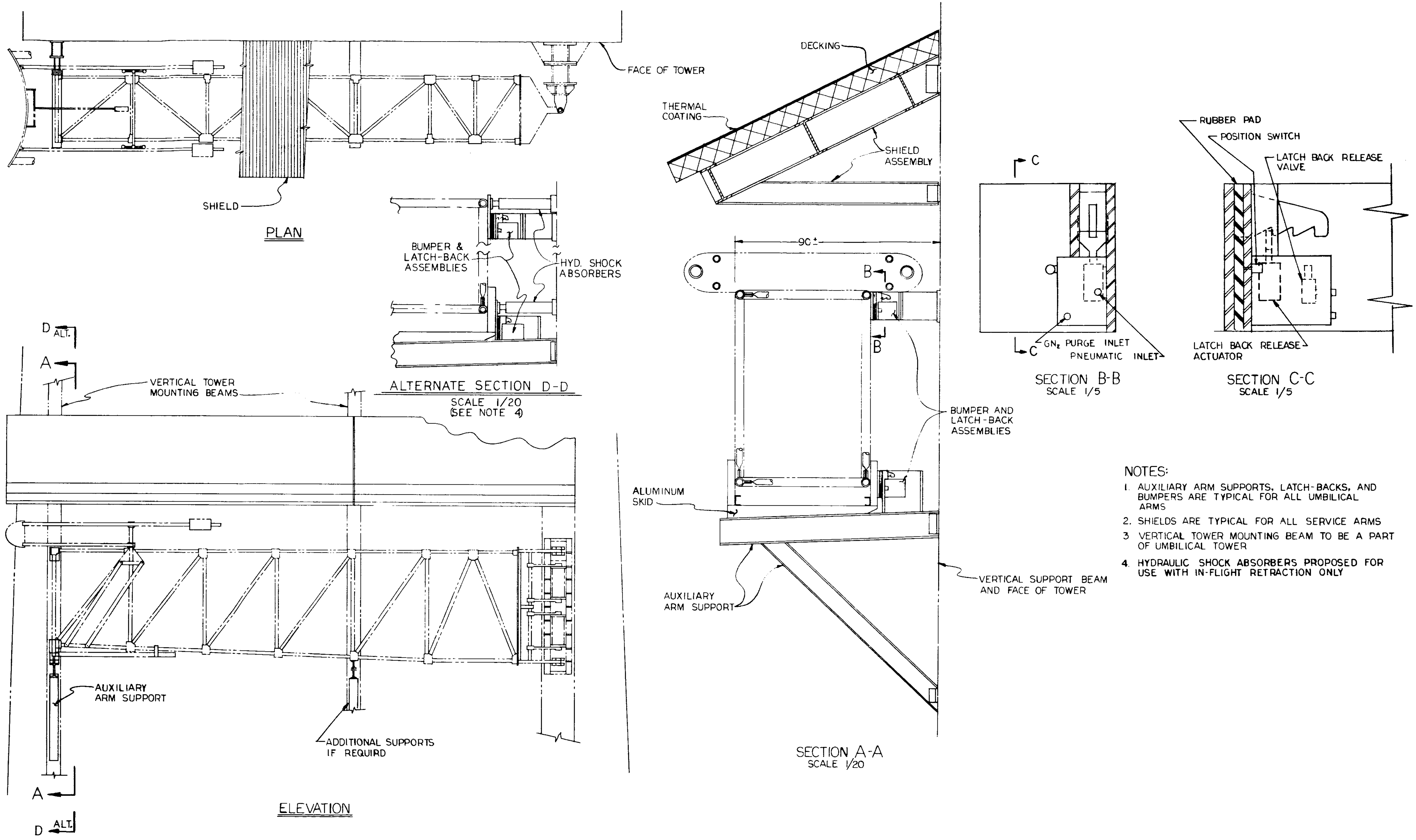

Figure 7-17. Auxiliary Support and Latch-Back and Shield

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The latching mechanism consists primarily of a spring-loaded cylinder which operates the latch assembly. A latch plate would be attached to the umbilical arm and would extend into the latching mechanism when the arms are in the fully retracted position. A manual switch would provide for unlatching. The latching mechanism provides a simple method of securing the umbilical arms in their retracted positions during the high blast pressure and vibrations which occur during vehicle launch. It also provides for thermal expansion of the arm due to the increase in temperature during launch.

H. SERVICE ARM SHIELD

Because of high temperatures and exhaust velocities which would occur during vehicle launch, a shield for protecting the service arms was considered as shown in figure 7-17, section A-A. The shield would be constructed with heavy roof decking supported by wide flange steel beams. The decking will be treated to withstand the blast temperatures and will be designed to transfer the blast loads to the supporting beams. At the present time, there is no information available concerning the nature or magnitude of the blast loads. The disadvantages to using such a shield are:

1. The shield must extend from the face of the tower to the outer edge of the outside fuel line.

2. The bottom of the shield supports or framing must allow

clearance above the service arms to avoid interference with the umbilical disconnect device.

3. A shield to support large blast loads would be heavy, thus requiring an additional vertical mounting beam in the tower.

4. Where service arms are spaced close together vertically, there would be interference between the lower service arm's shield and the upper service arm's auxiliary arm support and access platform framing.

5. Due to the nature of the vehicle blast it is doubtful if the shield will protect the outer umbilical lines and service arm truss.

6. Service arm shields must be relocated as the arms are relocated.

Because of these disadvantages and the doubtful effectiveness of a service arm shield, it is desirable to use some other method of protecting the service arms from blast. One method would be to apply a protective coating material to all components of the service arm. The effectiveness of this method cannot be determined until the nature and magnitude of the blast loads and temperatures are known and tests have been performed.

I. AUXILIARY ARM SUPPORT

Auxiliary arm supports (figure 7-17) should be provided to help support the service arms when in the fully retracted position. These

supports are needed to help carry the umbilical arms during the time of high temperatures, blast loads, and vibrations which occur at vehicle launch. The supports will be attached to an umbilical tower vertical mounting beam near the vehicle end of the umbilical arms. If the loads during vehicle launch are excessive, more supports can be added between the end support and hinge. These additional supports would require an additional tower mounting beam.

The top of the supports may either be sloped as shown in the figure as section A-A, or level as shown in a sketch in Appendix B. The sloped support is preferred. A skid will be attached to the bottom of the service arms. The skids will be made of aluminum to reduce the possibility of sparking upon contact with the supports. If additional provisions are required against sparking, the top of the auxiliary arm support may be either coated with a nonsparking material or positioned slightly below the bottom of the skid. Any downward loads applied to the arms will cause them to deflect and rest on the supports.

J. BASIC ARM STRUCTURE - APOLLO ACCESS ARMS

1. Proposed Configuration.

The configuration of the proposed Apollo access arms is shown in figure 7-18.

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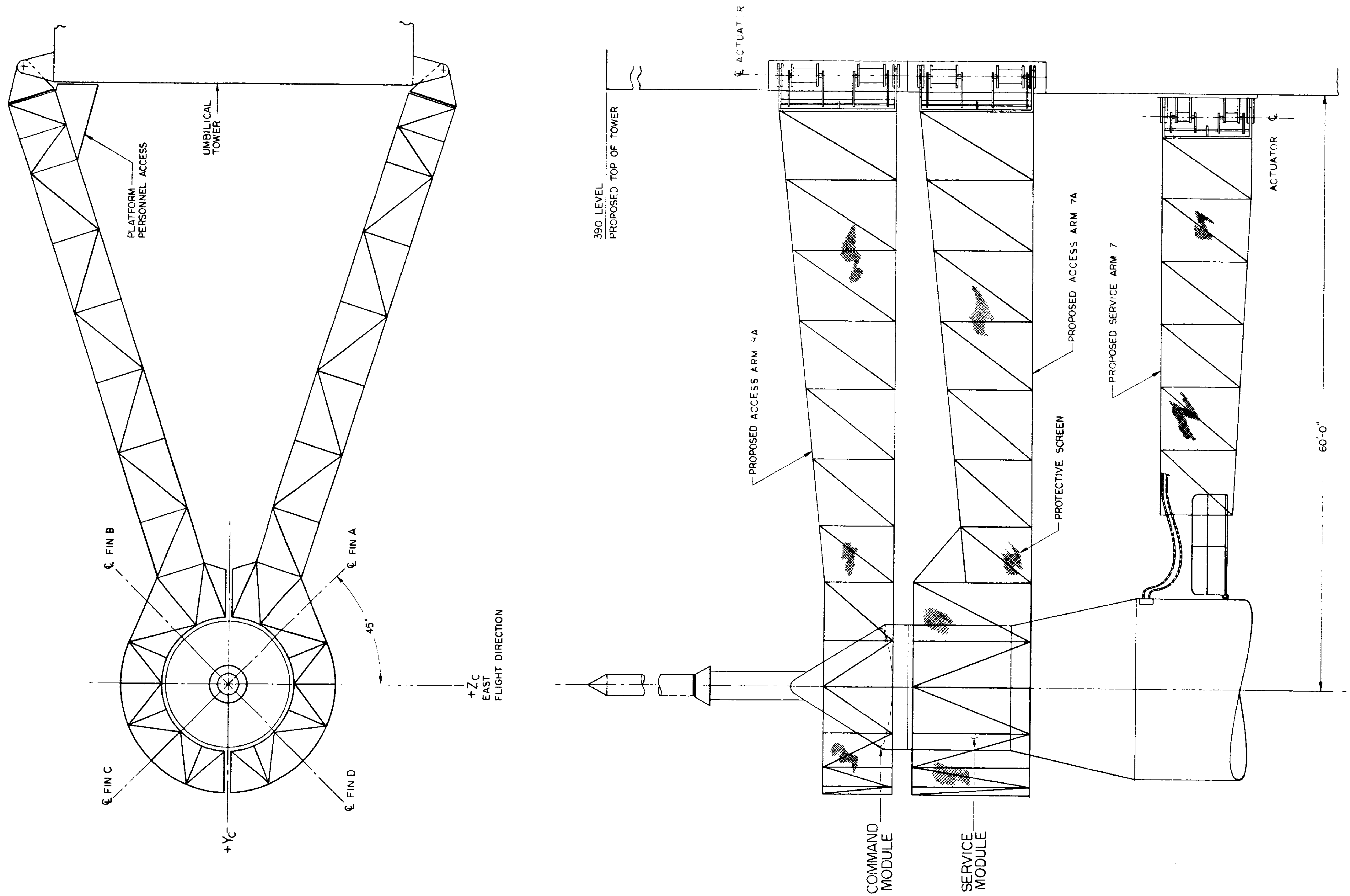

Figure 7-18. Apollo Access Arm Elevation and Plan View

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The truss should have a minimum clear height inside of 78 inches and a minimum clear width inside of 42 inches. Length of the platform is determined by the specified 720-inch dimension from the center of the vehicle to the face of the tower and by the fact that there must be a clearance all around between the vehicle and the platform. See Section VI for vehicle deflection curves.

A tapered truss would be a more practical design than one with a constant depth. The taper would permit the depth to vary with the moment in the truss, thus effecting a more efficient utilization of material. The depth of 144 inches shown in figure 7-19 for the end of the truss nearest the tower would require 5-1/2 inch OD tube as chord members. Tubular members appear to be the best choice because they offer the same radius of gyration about any axis. They also have a larger, least-radius-of-gyration-to-weight ratio than any other cross section.

For the trusses in the vertical planes, a "Pratt" truss would be best suited because its diagonals would always be in tension, and the shorter vertical members always in compression, while supporting vertical loads. For the trusses in horizontal planes, a "Warren" type truss would be best suited because of the possibility of a reversal in the direction of the wind and possible dynamic loads.

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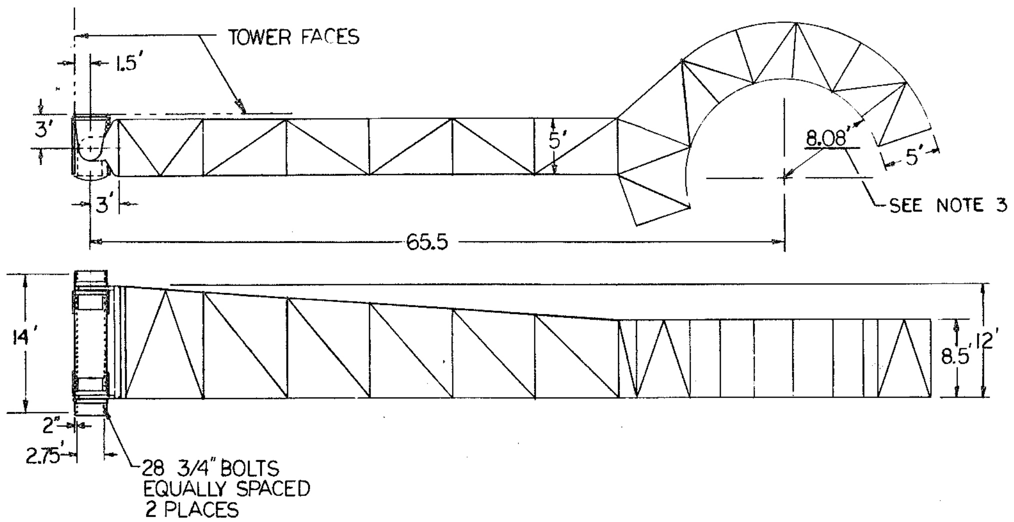
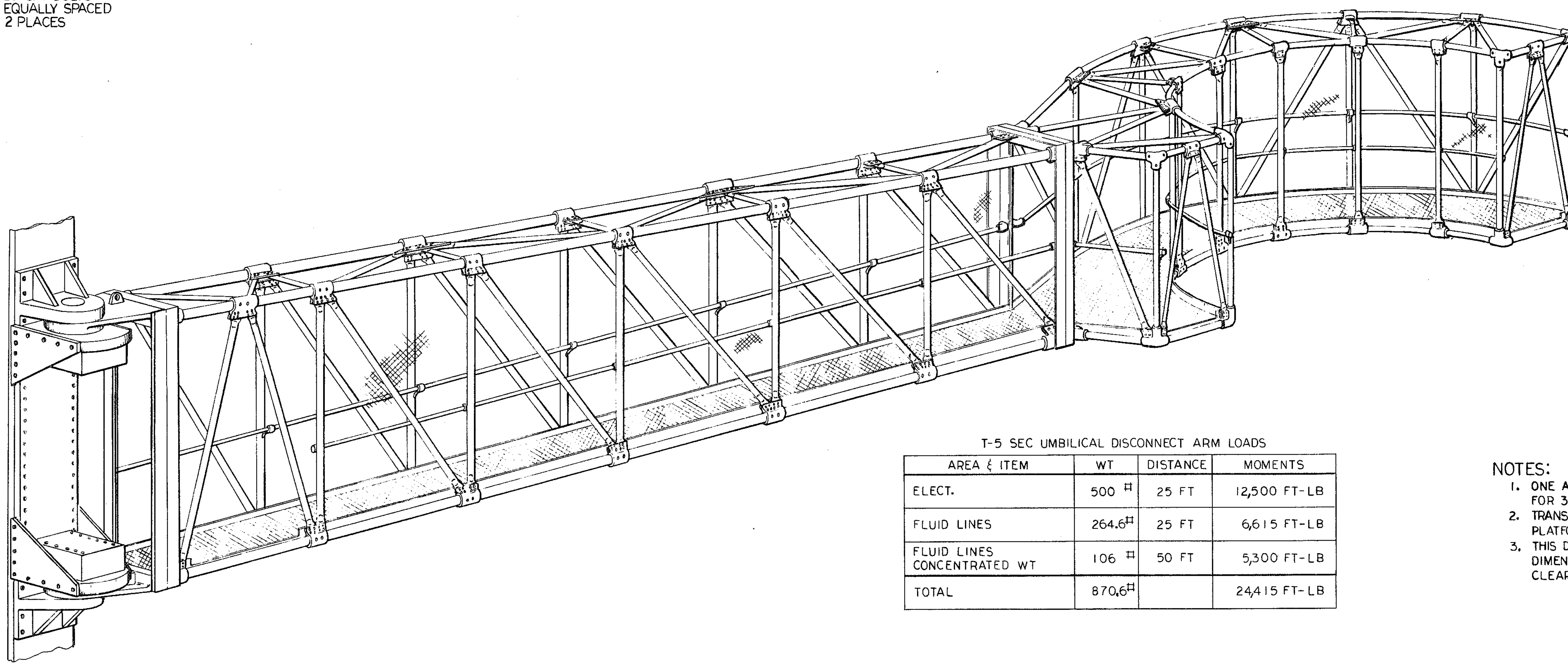


COMMAND MODULE ARM LOADS

AREA & ITEM	WT	DISTANCE	MOMENTS
LINES ON CIRCULAR PORTION OF ARM	177#	60 FT	10,620 FT-LB
LINES ON STRAIGHT PORTION OF ARM	311#	25 FT	7,780 FT-LB
ELECT. ON CIRCULAR PORTION OF ARM	160#	60 FT	9,600 FT-LB
ELECT. ON STRAIGHT PORTION OF ARM	1,000#	25 FT	25,000 FT-LB
VICINITY EQUIP	150#	40 FT	6,000 FT-LB
MEN (9 AT 250# EA)	2,250#	60 FT	135,000 FT-LB
TOTAL BOTH HALVES OF ARMS	4,048#		194,000 FT-LB
TOTAL EACH HALF OF ARM	2,024#		97,000 FT-LB

SERVICE MODULE ARM LOADS

AREA & ITEM	WT	DISTANCE	MOMENTS
ELECT. ON STRAIGHT PORTION OF ARM	1,000 #	25 FT	25,000 FT-LB
LINES ON STRAIGHT PORTION OF ARM	1,733.5#	25 FT	43,338 FT-LB
ELECT. WTS CONCENT-RATED ON ARM	140 #	50 FT	7,000 FT-LB
LINE WTS CONCENT-RATED ON ARM	1,040 #	60 FT	61,200 FT-LB
MEN (3 AT 200# EA)	600 #		45,000 FT-LB
TOTAL BOTH HALVES OF ARMS	4,513.5#		181,538 FT-LB
TOTAL EACH HALF OF ARM	2256.75#		90,769 FT-LB



T-5 SEC UMBILICAL DISCONNECT ARM LOADS

AREA & ITEM	WT	DISTANCE	MOMENTS
ELECT.	500 #	25 FT	12,500 FT-LB
FLUID LINES	264.6#	25 FT	6,615 FT-LB
FLUID LINES CONCENTRATED WT	106 #	50 FT	5,300 FT-LB
TOTAL	870.6#		24,415 FT-LB

NOTES:

1. ONE ARM SHOWN (1 LH & RH REQUIRED FOR 360° ACCESS.)
2. TRANSITION PLATFORM BETWEEN RING PLATFORM AND VEHICLE NOT SHOWN.
3. THIS DIMENSION APPROXIMATE, FINAL DIMENSION DEPENDS UPON SWAY CLEARANCE NEEDED.

Figure 7-19. Apollo Access Arm Basic Structure

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The walkway floor could be expanded-aluminum grating, except for the portion that encircles the vehicle. This flooring would have openings small enough to prevent wrenches, screwdrivers, etc., from falling through. All flooring would have a raised or serrated, nonskid surface. Handrails would be provided for the full length of the walkways. "White room" facilities will be required around the personnel entry hatch of the Command Module.

2. Personnel Safety.

Requirements for personnel safety would be the same as discussed for the service arms.

3. Arm Loading.

a. Static Loads.

The dead load of the arms is estimated from preliminary calculations to be 110 pounds per foot (Appendix B). This includes the weight of the truss framework, the walkway flooring and its supports, handrail, and an allowance for the weight of any umbilical lines. A load factor of two would be used with dead load, based on the yield strength of the material.

The critical live load would consist of nine men, who, with equipment, weight 250 pounds each. These nine men would include three spacecraft crew members and six support personnel. A load factor of six would be used with live load.

The wind velocity values, which would be used in the design of the Apollo access arms, are shown on the charts in Section VI. A load factor of two would be used with survival windload.

b. Dynamic Loads.

Since the Apollo access arms would be retracted prior to lift-off, dynamic loads would present no critical design conditions.

4. Structural Material, Properties, Design Data, and Allowables.

All information pertaining to the structural material properties, design data and allowables, would be the same as discussed for the preceding service arms.

5. Arm Characteristics.

a. Deflections.

Based on preliminary calculations (Appendix B), the approximate dead load and live load deflections are 1.41 inches and 1.03 inches respectively. This indicates a minimum total deflection of approximately 2.5 inches at the outer ends of the arms.

b. Mass Moment of Inertia Estimate.

Based on preliminary calculations (Appendix B), the mass moment of inertia of the Apollo access arms is estimated to be 5,170,000 lb-in.-sec.^{2}

c. Solidity Ratio and Drag.

A solidity ratio of 40 percent was used in the preliminary

calculations shown in Appendix B. Calculations indicate a solidity ratio of approximately 30 percent for the bare Apollo access arms; however, it is felt that with the possibility of umbilical lines, "white room", and other equipment being added, the 40 percent figure would not be too conservative. A 40-percent solidity ratio, and winds as shown on the chart in Section VI, give a maximum drag on the platform of approximately 11 pounds per square foot and a drag of approximately 8 pounds per square foot under launch conditions.

6. Latching Mechanisms.

Latching mechanisms would be necessary to hold the arms together while they are in an extended position. These latches would be of a type that would transfer some of the live load shear and moment due to live load eccentricity from one arm to the other. This would cause the two arms to act partially as a unit, thus reducing the live load deflection and the stresses in the truss members.

These latches could be either manually or remotely controlled, and contain safety locks. Personnel safety requirements seem to eliminate a manual type. A proposed latch of each type is shown in Appendix B.

7. Movable Stands.

At the elevation of the Apollo access arms, wind will cause a deflection of the vehicle and tower. To provide for the possibility

that these deflections might be accumulative, sufficient clearance should be provided between the Apollo access arms and the vehicle. To bridge this gap, movable stands, that are free to move in any direction, should be provided. As many stands as necessary to permit access to all work points and to the spacecraft hatch should be provided.

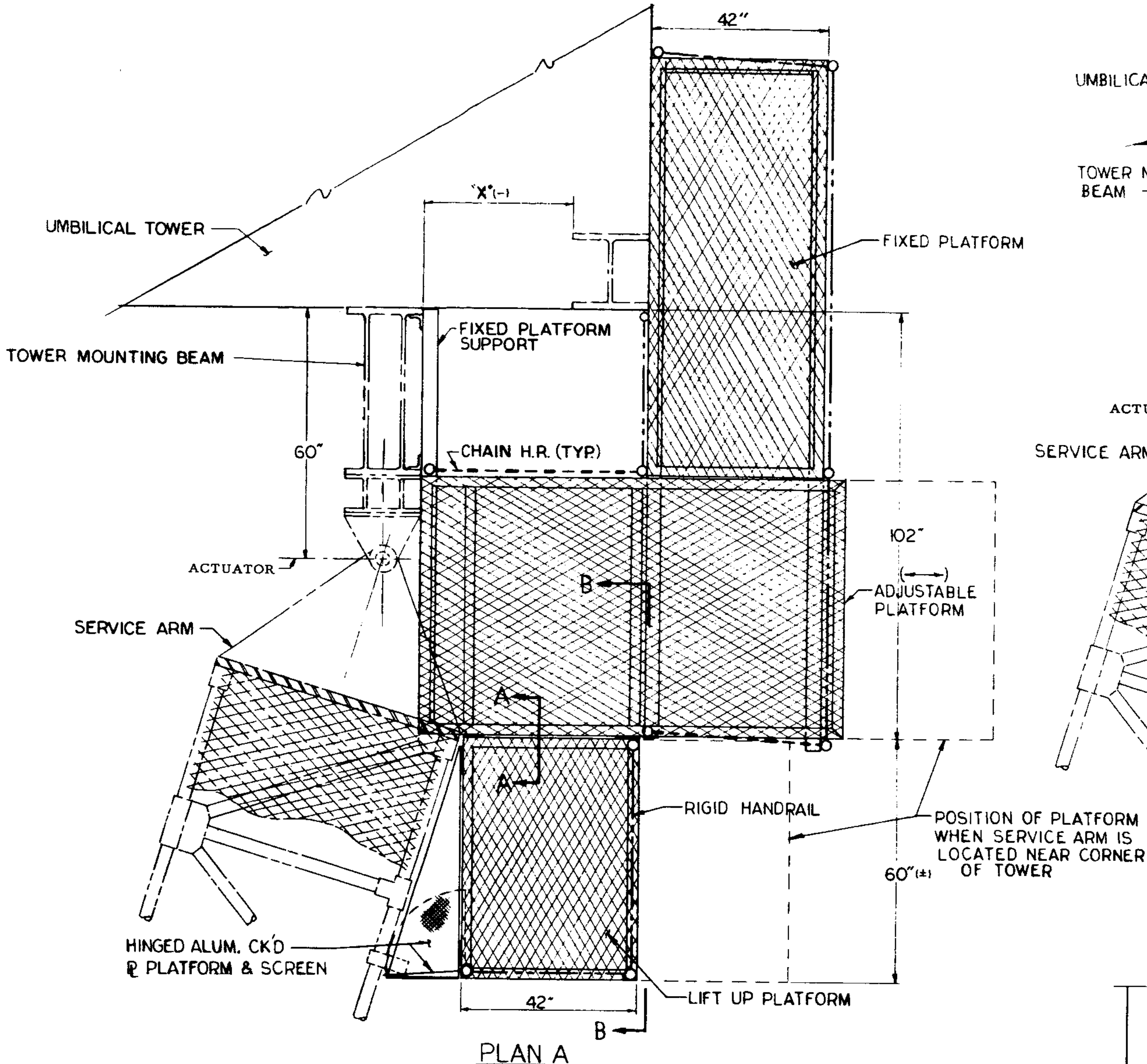
K. ENTRANCE PLATFORMS

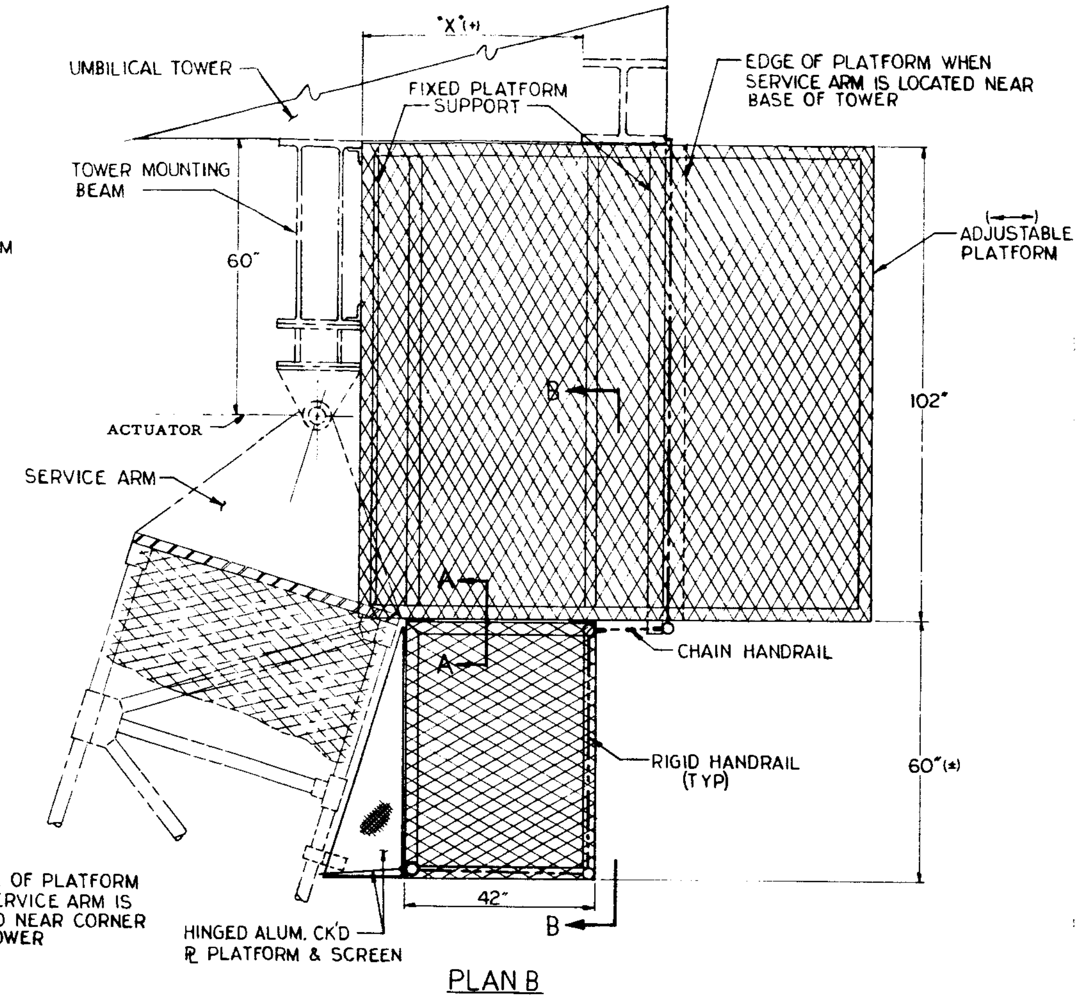
Platforms would be provided to permit access from the tower to the walkway in the umbilical arms as shown in figures 7-20 and 7-21. The flooring of these entrance platforms would be of the same type as used for the walkways in the umbilical arms. Handrails and safety screening would be provided on all open sides of the platforms.

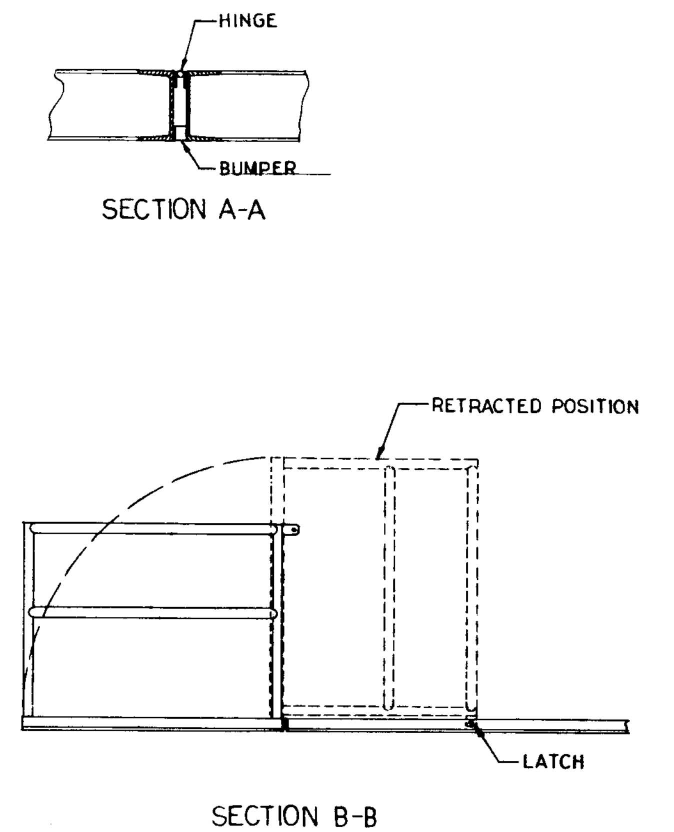
L. ARM CONTROL SYSTEMS

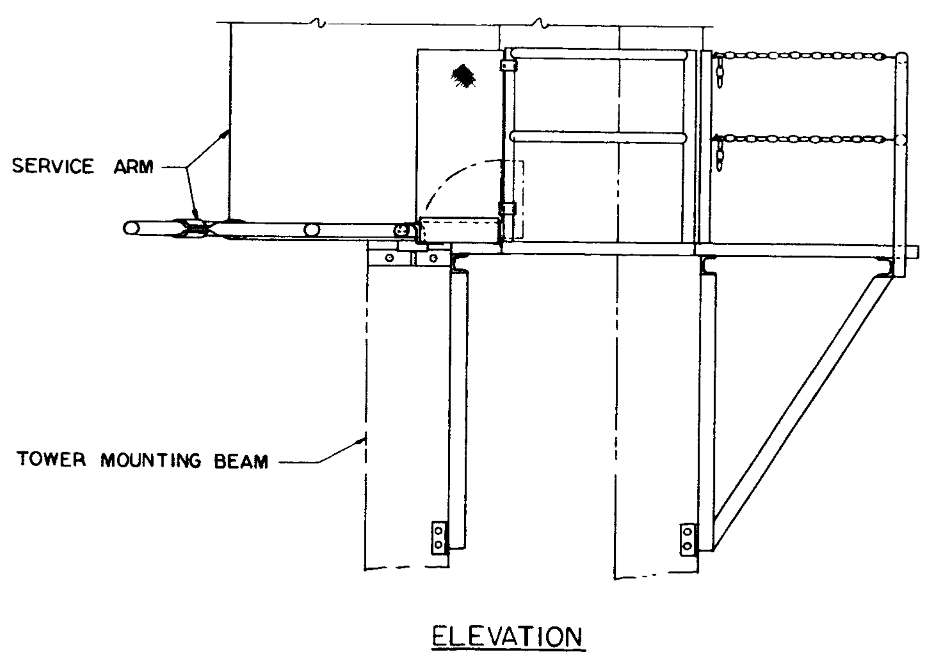
1. Service Arm Electrical System.

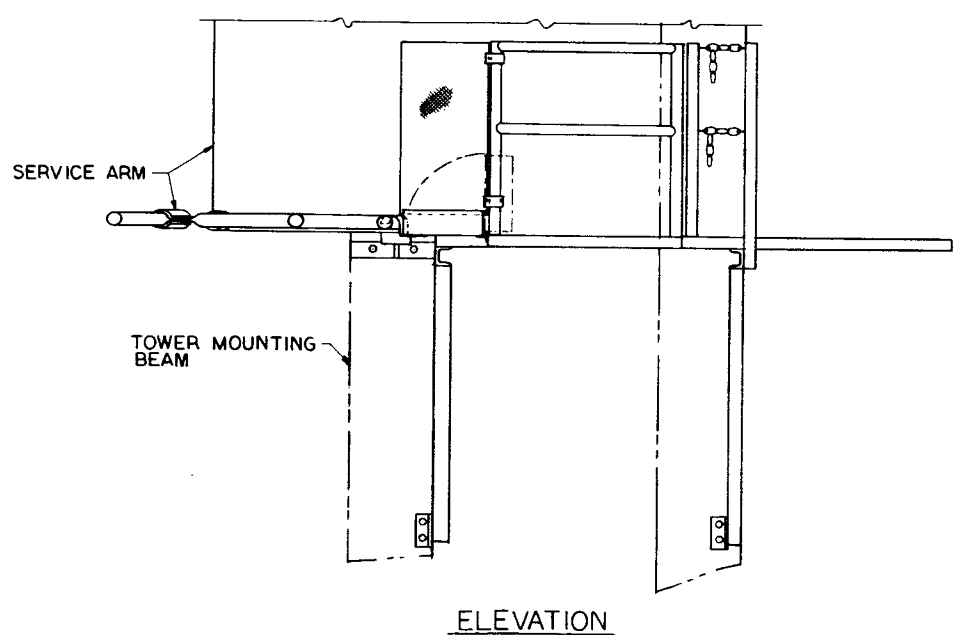
The service arm electrical power will be provided by the facility power system. Electrical power requirements include a 28-volt dc power source for all control, indication, and communication circuits pertinent to the service and access arms and a 120/240-volt single phase ac power source for tower and arm flood-lighting and tower convenience outlets; and a 240-volt three phase ac power source for the hydraulic pump unit located at the base of the umbilical tower in the Automatic Ground Control (AGC) area.











NOTES:
1. PLATFORMS SHOWN ARE TYPICAL FOR ALL SERVICE ARMS ACTUATED BY INBOARD MOUNTED ROTARY UNITS.
2. TOWER STRUCTURAL MEMBERS TO BE DRILLED AS REQUIRED TO ALLOW PLATFORMS TO BE POSITIONED CORRECTLY AT ANY SERVICE ARM.
3. PLAN "A" WOULD BE USED WHEN DIMENSION "X" IS LESS THAN 42 IN.

Figure 7-20A. Service Arm Entrance Platforms Concepts

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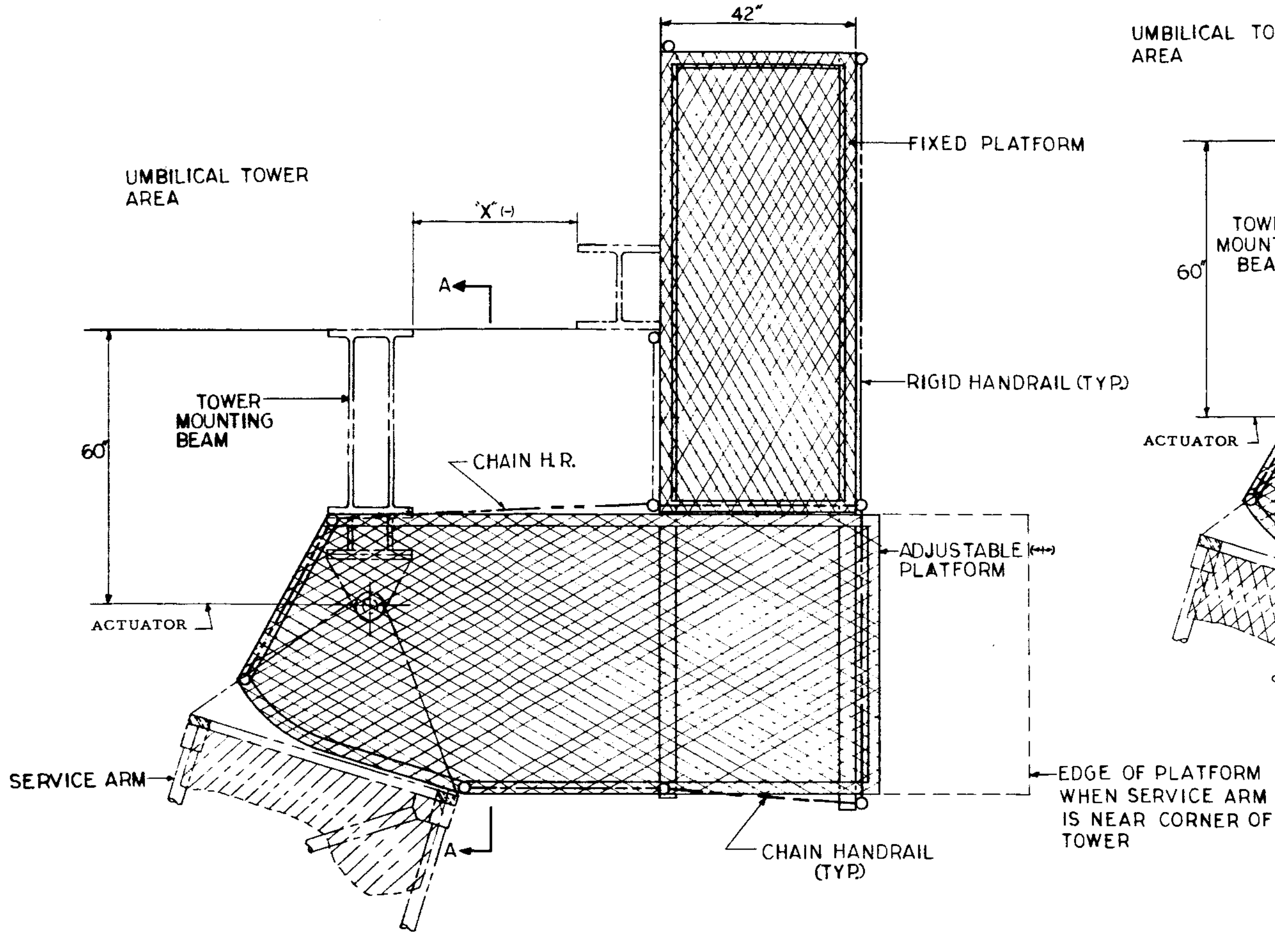

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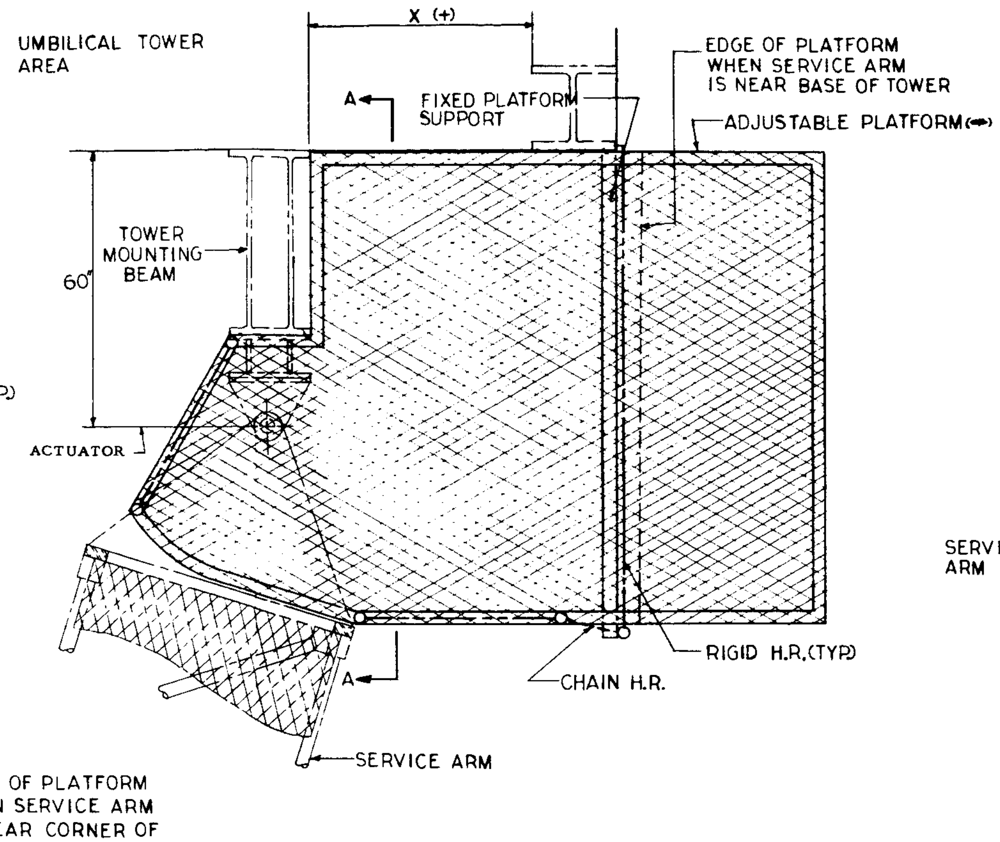
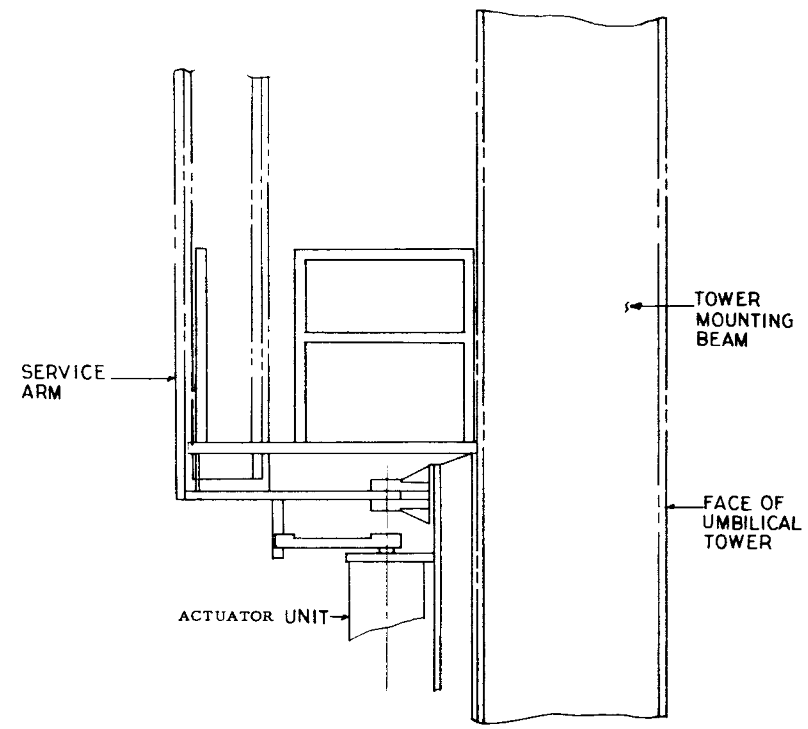
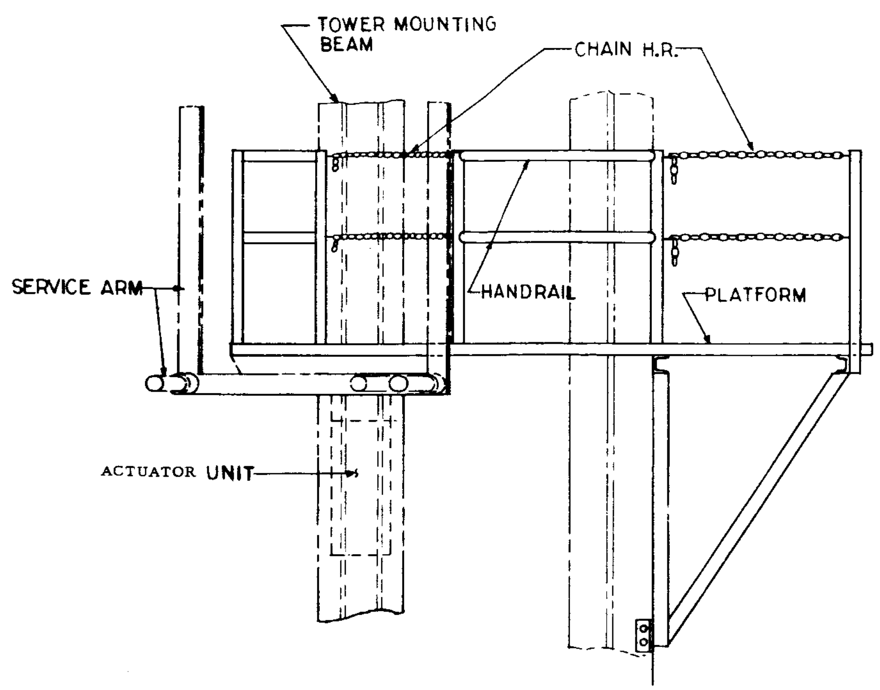


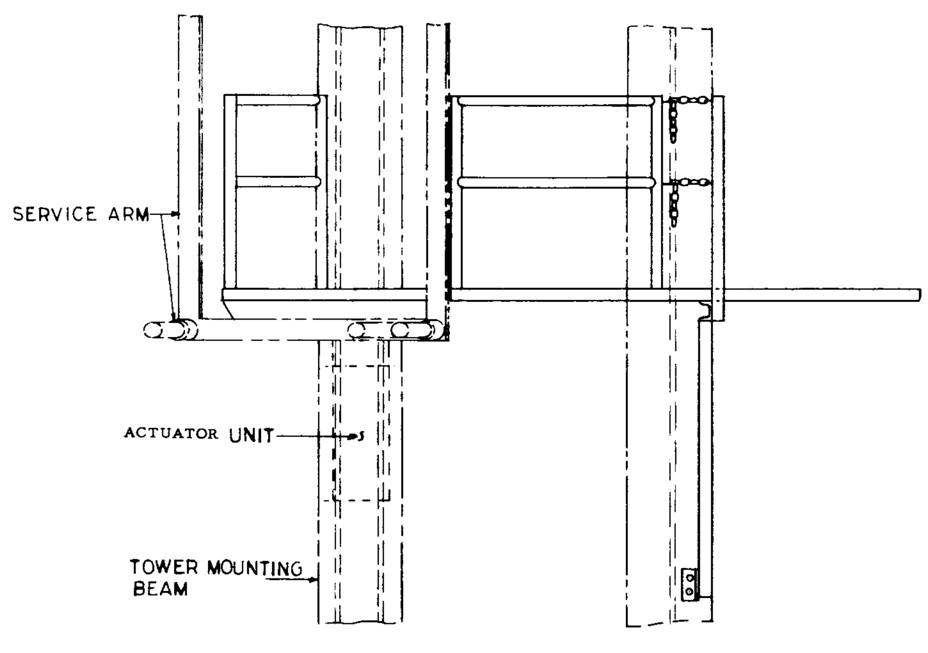
-PLAN B-



-SECTION A-A-



-ELEVATION-



-ELEVATION-

NOTES:

1. PLATFORMS SHOWN ARE TYPICAL FOR ALL SERVICE ARMS ACTUATED BY OUTBOARD MOUNTED ROTARY UNITS.
2. TOWER STRUCTURAL MEMBERS TO BE DRILLED AS REQUIRED TO PERMIT CORRECT POSITIONING OF PLATFORMS AT ANY SERVICE.
3. PLAN "A" WOULD BE USED WHEN DIMENSION "X" IS LESS THAN 42 IN.

Figure 7-20B. Service Arm Entrance Platforms Concepts

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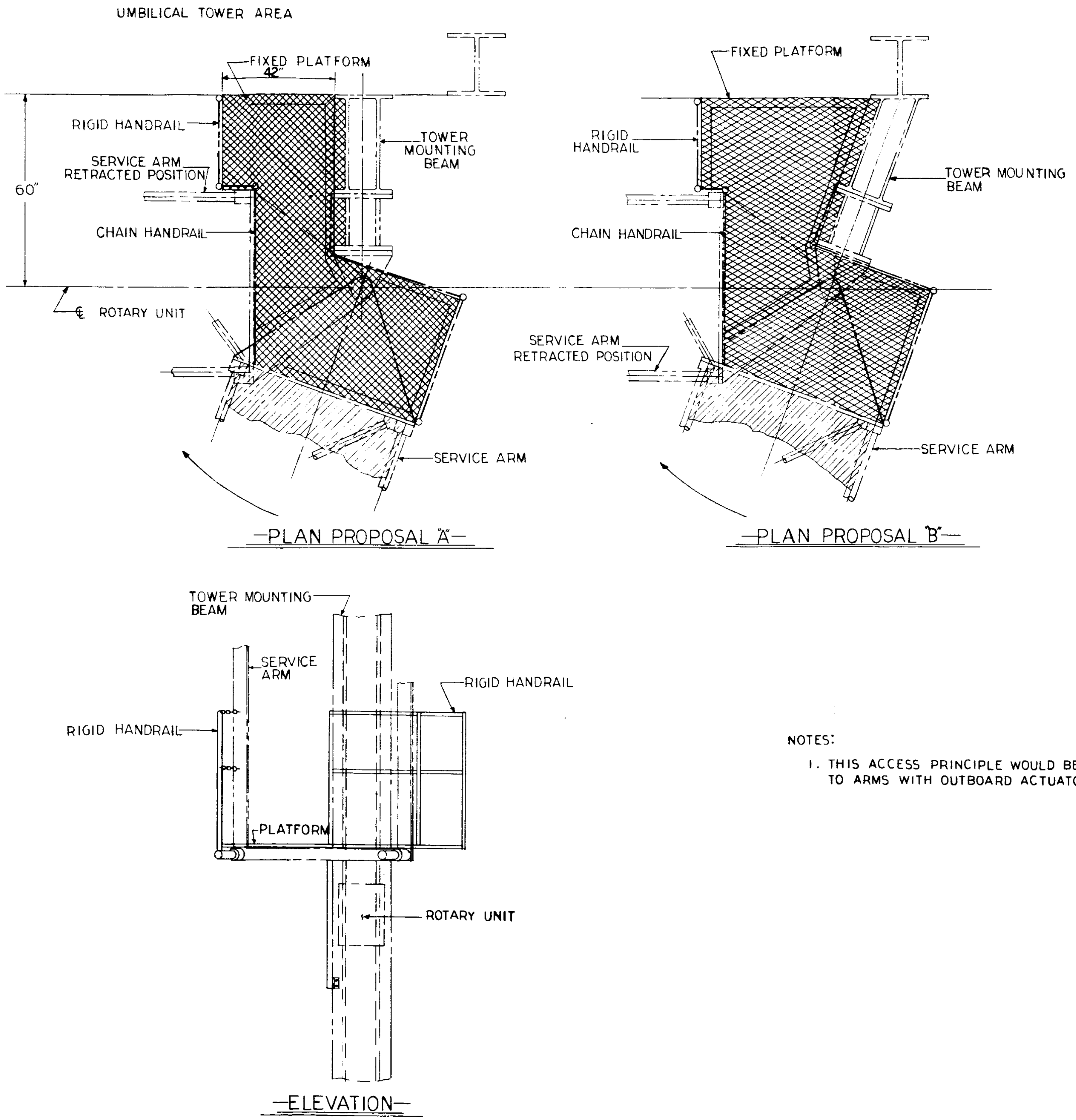

NOTES:

1. THIS ACCESS PRINCIPLE WOULD BE APPLICABLE TO ARMS WITH OUTBOARD ACTUATORS.

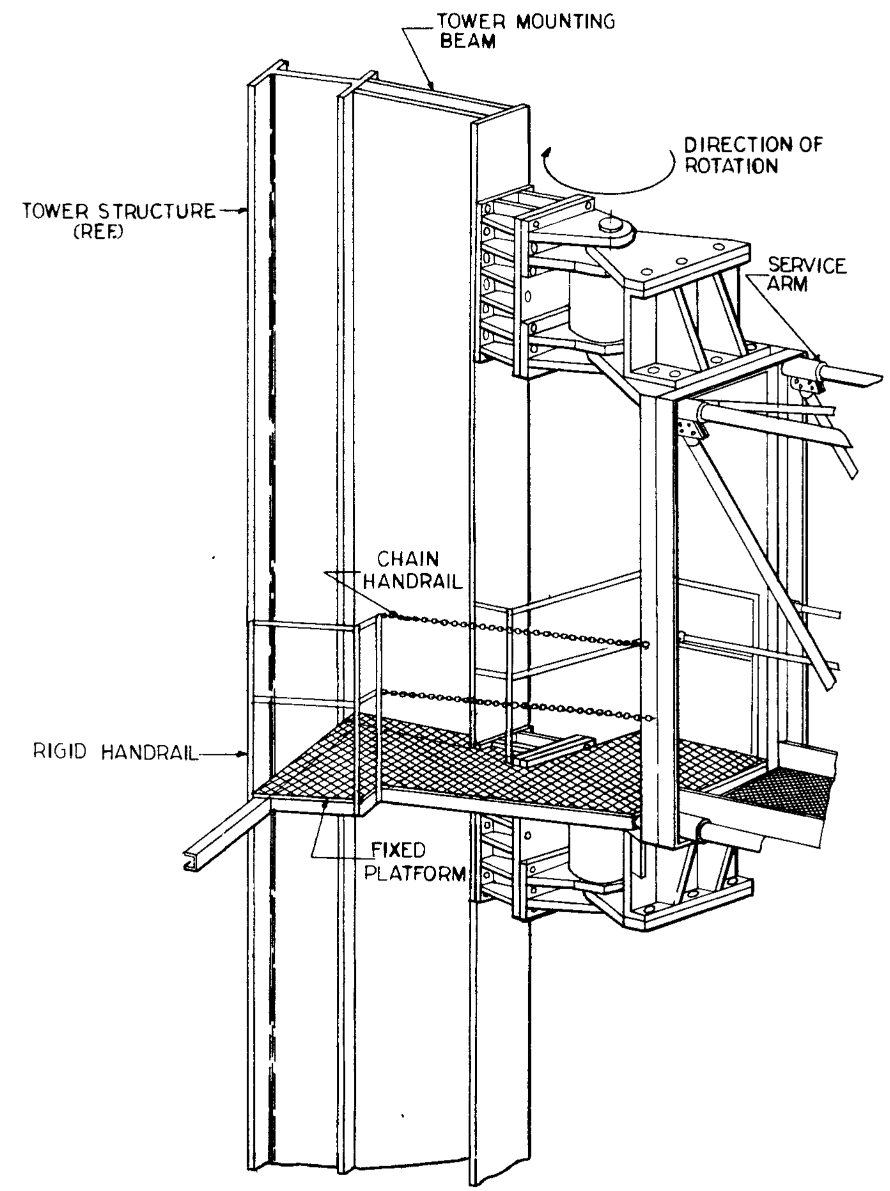

Figure 7-20C. Service Arm Entrance Platforms Concepts

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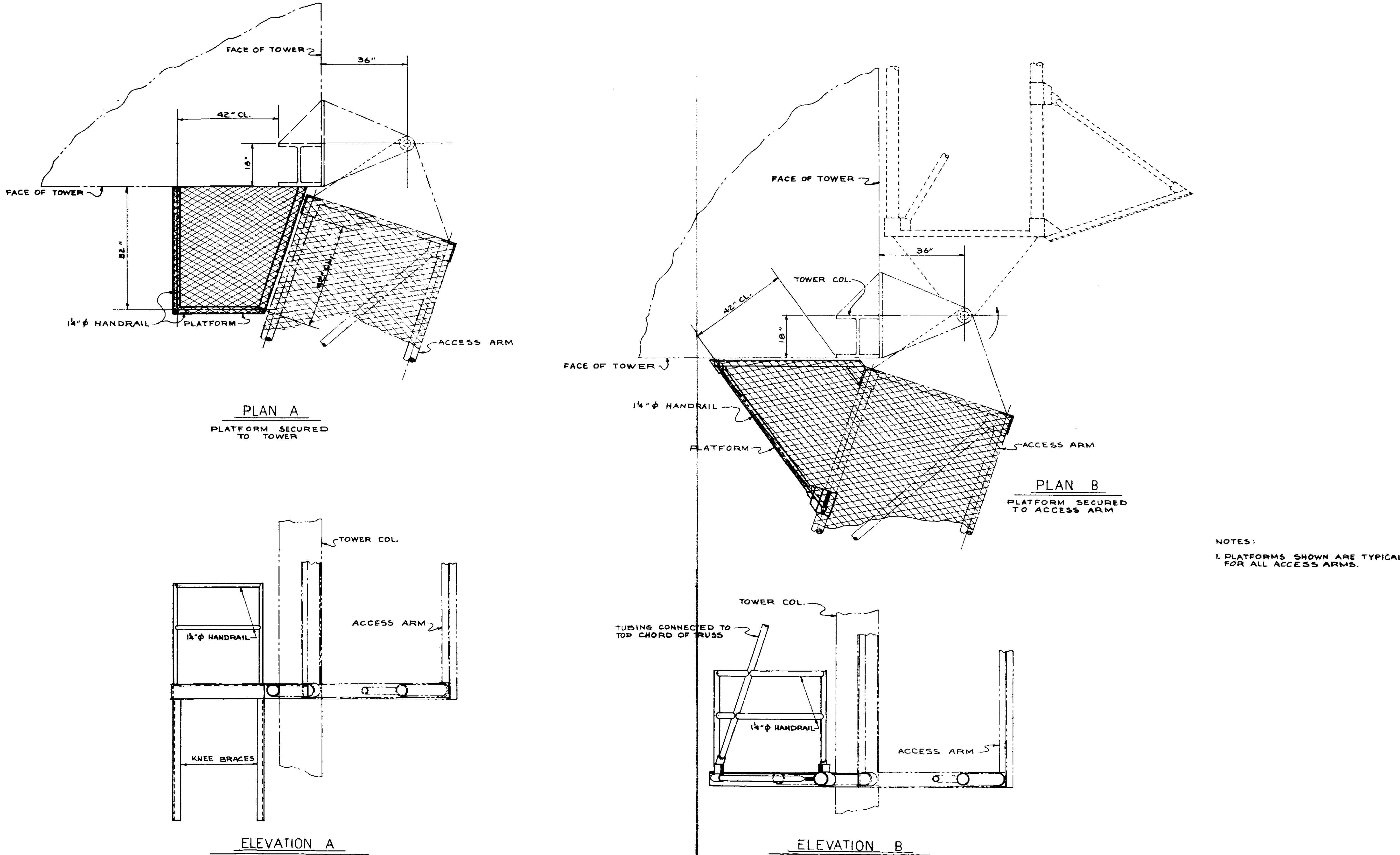

Figure 7-21. Apollo Service Platform Concepts

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The 28-volt dc system will have a standby battery bank located as close as practical to the arm mechanisms connected in parallel with the dc generators. To provide for protection from generator short circuit conditions, there will be diodes inserted in the lines on the generator side of the buss. These power diodes will be sufficiently derated to increase their reliability factor. An example of the arrangement is given in Appendix B. The battery bank will have a floating charger connected across its output terminals to continually assure a "ready to operate" battery condition at all times in case of dc generator failure. The battery bank capacity will be 400 ampere-hours. Battery size determination is shown in Appendix B.

Included in this proposal are three umbilical arm electrical control and indication systems. These are: (1) inflight service arm electrical system, (2) prelaunch service arm electrical system, and (3) access arm electrical system. All electrical system drawings may be followed through by referring to the "Operational Sequence" portion of this report. All initial control functions and all indicator lamps (with the exception of AGC area hydraulic pump control, as explained later) are located at the launch control center. All manually operated switches marked ILCC (Independent Launch Control Center) are located on one of the three control and indication panels in the

Launch Control Center (LCC). These panels are (1) access arms control panel, (2) service arms control panel, and (3) hydraulic pump control panel.

There are two practical approaches to the arm control problem. The approach of disconnecting and retracting several service arms prior to hold-down release adds immensely to the reliability of the entire retraction system due to the fact that there are less arms to retract after lift-off. This approach calls for disconnecting and retracting service arms 2, 3, 5, and 7 before lift-off and after thrust commit. Service arms 4 and 6 are to be retracted after lift-off. The other approach is to disconnect and retract service arms 2, 3, 4, 5, 6, and 7 after lift-off. In both approaches, the access arms and service arm 1 are retracted prior to lift-off.

The inflight electrical system provides for monitor indications in the LCC with no control switches. Manual extension and retraction capability is provided on the umbilical tower.

The prelaunch electrical system provides for control and indications of retraction and extension in the LCC. There is also the capability of manual extension and retraction on the umbilical tower.

The access arm electrical system provides for control and indications of retraction and extension in the LCC. There is again the capability for manual extension and retraction on the umbilical tower.

In addition to the electrical controls described in the Operational Sequence, there are controls and indications provided in the LCC for operation of the hydraulic pump and indications of the various service arm and access arm component positions. These circuits serve to indicate states of readiness or malfunction of the systems.

The proposed inflight, prelaunch, and access arm electrical system functions as described in the Operational Sequence are put forth for clarity in the simplest form. As is shown on the electrical systems schematics, there are low current control relays interposed between the LCC manual switches and the power circuit supplying current to the solenoid operated hydraulic and pneumatic control valves at the arm locations. If the LCC to umbilical tower distance should be 10,000 feet or more, the negative side of the low current control lines should be picked up at the relay location without returning to the point of actuation. The same technique should be used on indicator lights. Thus, in both cases the facility negative buss is used for the return. A typical sample of the voltage drop encountered is shown in Appendix B. It may be necessary in some circuits that require a high current (more than 2 amperes) to insert a power relay between the smaller control relay and the solenoid operated valve. Since actual components have not been definitely sized as to current requirements (due to differences in manufacturers) these power relays have not been included in

the electrical systems schematics. However, the capability does exist. If the extra relays are used, their operating time should be considered.

The communications system required is a three way system between each service and access arm location, the AGC area, and the LCC. Each position will have the capability to call all other positions as well as to listen. There will be one channel which is common to all stations. This will require a total of at least ten channels per station.

Flood lighting on the umbilical tower platforms and the service and access arms should provide for illumination in the order of magnitude of twenty foot-candles. Illumination on the vehicle at the connectors should be approximately the same. The number and type of lighting fixtures along with the required lamp wattage is determined as shown in Appendix B.

There will be requirements for 120-volt single phase ac convenience outlets on each service or access arm platform. There should be at least one 240-volt single phase ac outlet on each platform to supply equipment that may require it. If electrically driven hand tools are to be used on the service and/or access arms, an extension cable will supply the electric power to the tool from a convenience outlet on the platform. Power will be removed from all ac outlets before fueling of the vehicle is begun.

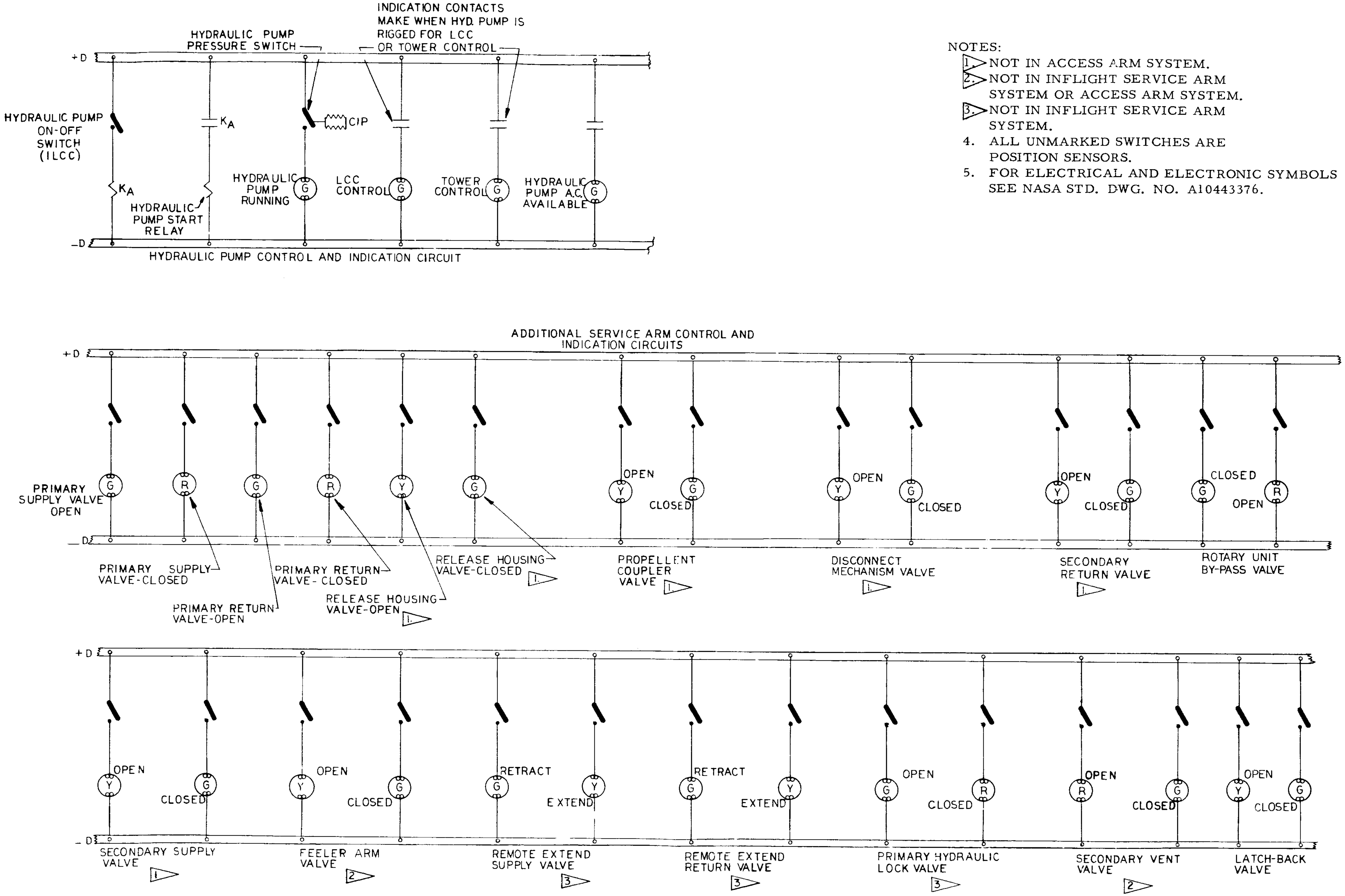
All electrical connections between the umbilical tower and

the AGC area will be routed through weatherproof connectors at junction boxes on the tower. The connected lines will be separated into four basic groups: (1) instrumentation circuits, (2) control and indication circuits, (3) communications circuits, and (4) power circuits.

Prior to a launch operation there should be certain prelaunch checks made to determine that the service and access arms are in proper operating condition. The prelaunch checks may be made at the service and access arms control panels in the LCC. All confirming or malfunction indications will be displayed by standard two-lamp indicators on the panel. As shown on the electrical system schematic drawings, the indicator lamps are energized by the closing of switches. The remaining confirm switches are position switches. All switches are hazardous area, hermetically-sealed-type devices. Latching, double solenoid actuated type valves are used at critical points in the umbilical systems. These valves insure additional reliability to the primary and secondary retract systems because once energized to a given position the valve will remain in that position even if electrical power is lost. All other solenoid operated valves are two position, energized or de-energized type. All solenoid and critical manually operated valves are to have position feedback switches for confirmation of operation.

The hydraulic pump system (figure 7-22) should be checked before launch to determine if it is ready to supply hydraulic fluid to any of the arms as needed. The LCC control lamp is energized on the LCC and AGC area hydraulic pump control panels to indicate that the hydraulic pump is rigged to be operated from the LCC using the hydraulic pump switch. If the pump is rigged to be operated from the AGC area panel, AGC control indicator lamps are energized on the LCC and AGC panels. A pump ac available lamp is energized on the controlling panels when three phase power is available to the hydraulic pump.

Service arm and access arm prelaunch checks are made at the LCC panels. Position switches close energizing indicators on the LCC panels when the hydraulic accumulators are filled with fluid. Position switches close to indicate proper positions of service arms, access arms, arm lock-pins, arm latch-back pins, hydraulic valves, and pneumatic valves. There is a hydraulic-pneumatic, system-ready "summation circuit" for each arm. These circuits are composed of relays in series, which when all are closed, will cause an indicator to be energized. These relays are energized by closing of critical manual valve position switches and pneumatic pressure switches.



NOTES:
1. NOT IN ACCESS ARM SYSTEM.
2. NOT IN INFLIGHT SERVICE ARM SYSTEM OR ACCESS ARM SYSTEM.
3. NOT IN INFLIGHT SERVICE ARM SYSTEM.
4. ALL UNMARKED SWITCHES ARE POSITION SENSORS.
5. FOR ELECTRICAL AND ELECTRONIC SYMBOLS SEE NASA STD. DWG. NO. A10443376.

Figure 7-22. Service Arm Electrical Schematic - Additional Controls and Indications

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Pressure switches close, energizing indicators when the primary pneumatic accumulator pressures, secondary pneumatic accumulator pressures (not in access arm system), and the low pressure pneumatic accumulator pressures are as required. Pressure sensor test switches are to be mounted on the various arms, control panels, and indication panels. When closed in a typical circuit, the switch energizes a pressure sensor test valve which cuts off pneumatic pressure and vents the pressure sensor. (See figure 7-23.) If the sensor is operating correctly, the pressure "OK" lamp should be de-energized. If a requirement exists for certain indications from the service and/or access arms to be given to the various stage contractor consoles, this can be accomplished by paralleling the required indications at the service and/or access arms control panels.

Portable service arm and access arm test boxes that can be inserted in the system at the arm platform junction boxes are to be used for "on site" operational checkout of the arms.

2. <u>Hydraulic and Pneumatic Systems.</u>

a. General.

Separate hydraulic and pneumatic systems will be provided to satisfy the individual requirements of each umbilical arm.

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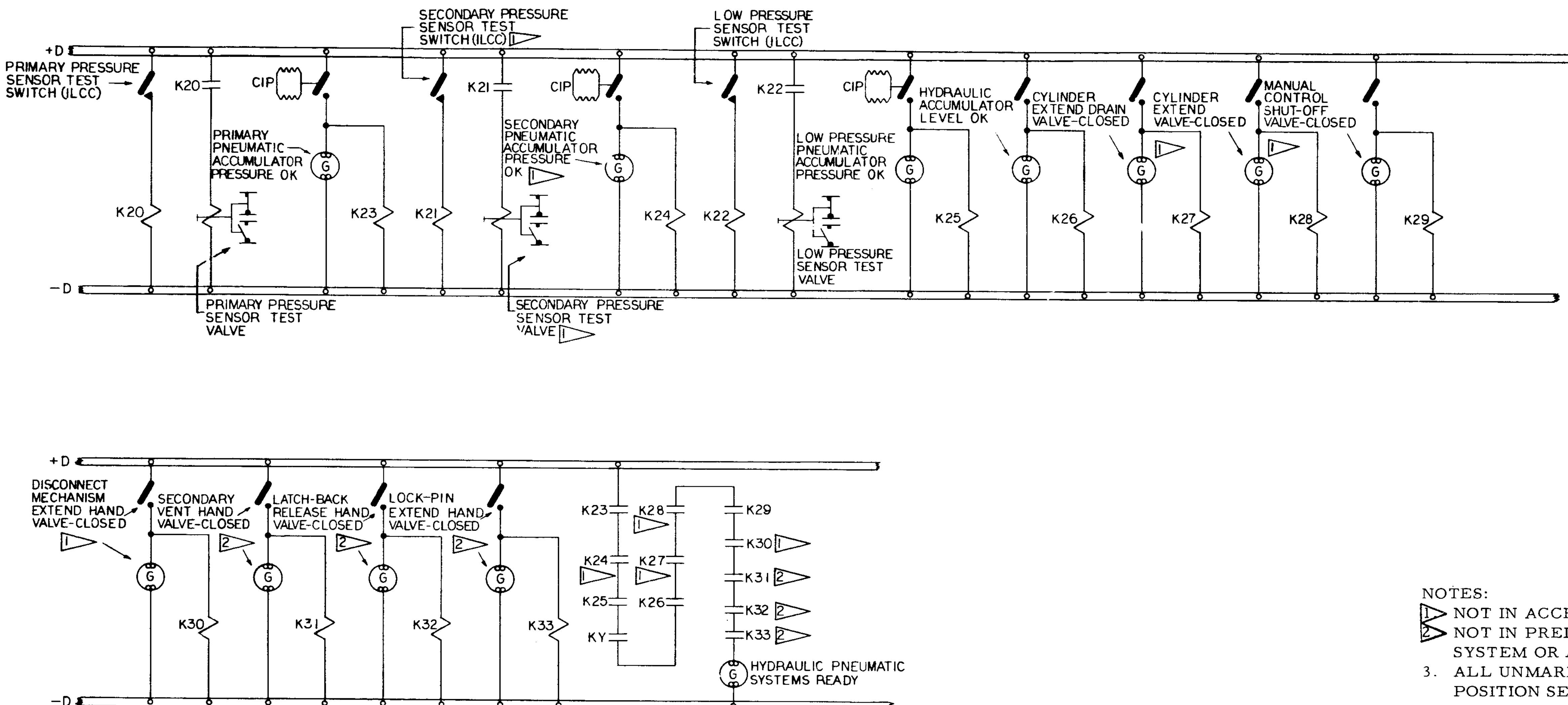

NOTES:
1. NOT IN ACCESS ARM SYSTEM.
2. NOT IN PRELAUNCH SERVICE ARM SYSTEM OR ACCESS ARM SYSTEM.
3. ALL UNMARKED SWITCHES ARE POSITION SENSORS.
4. FOR ELECTRICAL AND ELECTRONIC SYMBOLS, SEE NASA STD. DWG. NO. A10443376.

Figure 7-23. Service Arm Electrical Schematic - Additional Controls and Indications

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Each system will be capable of independent operation after all systems have been charged by a common hydraulic power cart and pneumatic supply. The components of each system will be carried by the umbilical arm or mounted on the umbilical tower adjacent to the arm. A tower mounted control panel will serve each umbilical arm. All hand valves, pressure regulators, and pressure gages, depicted in the applicable fluid schematic will be mounted on this control panel. The sources of the electrical signals which energize the various solenoid operated hydraulic or pneumatic valves are explained under operational sequence and/or electrical systems portions of this report.

Insofar as hydraulic/pneumatic requirements are concerned, the umbilical arms may be divided into four different types. These four types are: inflight retract service arm (all service arms to be retracted inflight), inflight retract service arm (to be used in conjunction with prelaunch service arms), prelaunch retract arm, and access arm. Similar characteristics of the two types of inflight service arms have permitted their combination into one schematic and one set of operational sequences. Therefore, three schematics and three sets of operational sequences are presented within this report which identify the function of the major components of each system. For most components, the specific type of hardware proposed and its general operating requirements will be evident. A brief discussion

follows for each subsystem or component which warrants further explanation. It will be noted that sizing considerations have been limited to only those actuators which produce rotation of the umbilical arms. The various low pressure pneumatic actuators may be sized upon determination of exact motion and load requirements.

b. Arm Rotary Actuation.

Double-vane type hydraulic rotary actuators are proposed to produce rotation of the arms. These units are ideally suited to the high torque requirements of the system and may be employed in place of single vane units since the angle of rotation is less than 100 degrees. In addition to the advantage of producing twice the torque of an equal size single vane unit, balanced thrust loads on the bearings of a double vane actuator allow high efficiency.

The S-II aft service arm has the highest torque requirements of all service arms and will govern the sizing of the actuators. The dynamic requirements were calculated to be: 710,000 in.-lb at maximum acceleration of .225 rad/sec^2 through an angle of 36.5 degrees in 3.0 seconds plus maximum deceleration torque of 960,000 in.-lb through 36.5 degrees. The additional deceleration torque is due to possible wind loading of the arm which may apply an external torque of 250,000 in.-lb. A pair of commercially available actuators, each rated for 741,000 in.-lb at 3000 psi, are proposed. These units

have a displacement constant of 260 in.^{3}/rad each or 520 in.^{3}/rad total. Acceleration torque may be achieved with a supply pressure of about 1450 psi. The return pressure during deceleration for maximum wind loading would approach 3000 psi to create the necessary pressure difference across the vanes. During full retraction, the pair of actuators would consume 2.9 gallons of hydraulic fluid and demand a maximum flow rate of approximately 91 gpm.

The primary cam valve should be designed to produce a decelerating torque equal to the value used for acceleration so that the summation of energy over the entire cycle approaches zero. Since the presence of accelerating wind loads is uncertain, wind loading will not be incorporated in the cam valve design. Consequently, hydraulic shock absorbers will be required to remove any excess kinetic energy acquired by the arm. These shock absorbers will be mounted on the umbilical tower near the latch-back mechanisms.

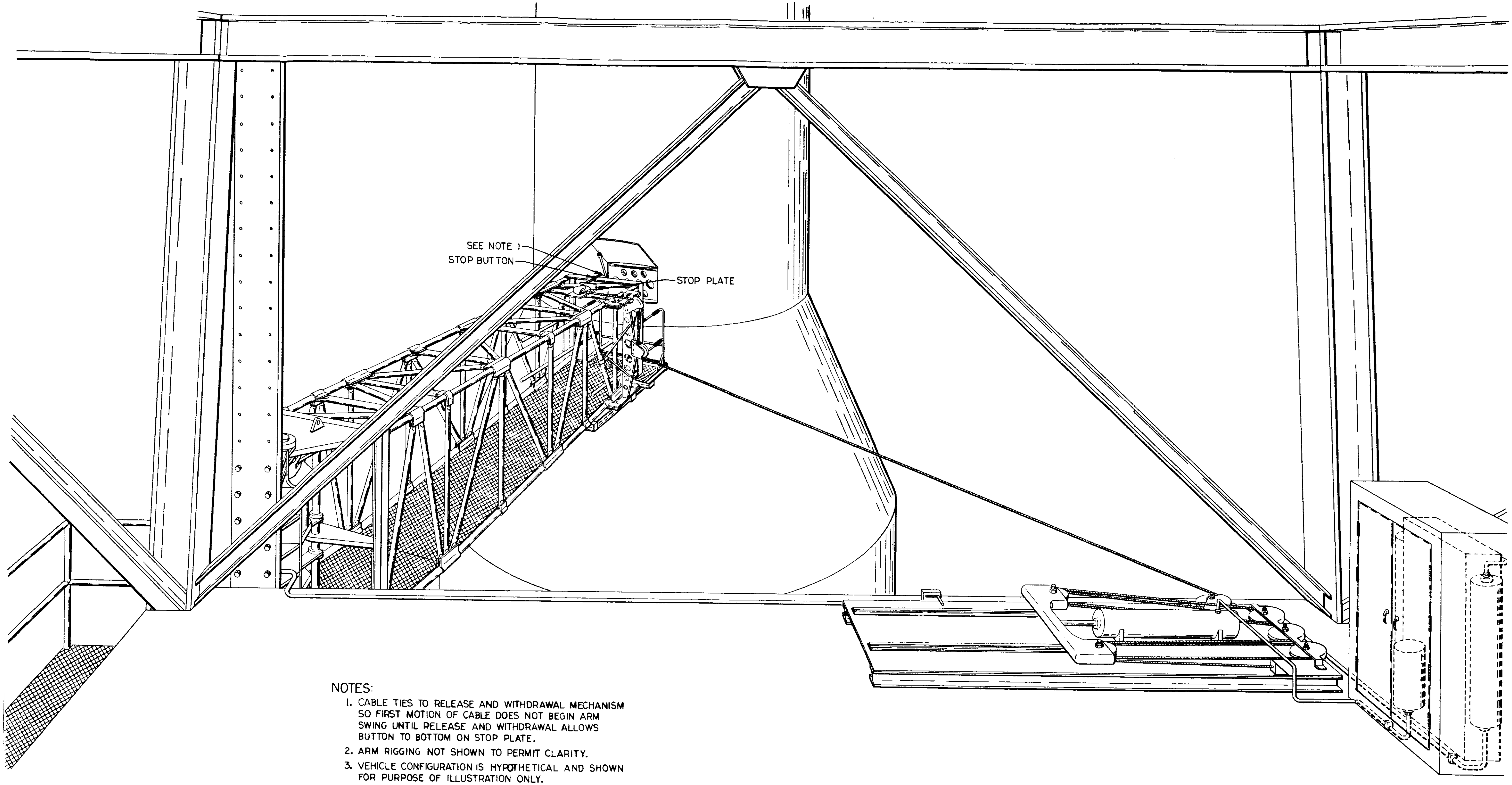
The S-IVB aft service arm has higher acceleration requirements than the other arms and consequently will govern valve and line sizing criteria. This arm is required to accelerate at .229 rad/sec^2 for 3.8 seconds which demands a maximum flow rate of around 117 gpm. The S-IVB aft arm has lower torque requirements than the S-II aft arm because of its smaller moment of inertia.

c. Secondary Retraction System (figure 7-24).

One secondary retraction system that has been suggested, would provide an emergency capability for service arm and lanyard retraction. Operation of this secondary system is remotely and automatically initiated by failure of the primary (rotary actuator) system as described in Operational Sequence (paragraph M. 1. b.).

This secondary system consists of a tower mounted high pressure pneumatic linear actuator which drives a cable through a pulley system. The cable is routed through a block and tackle type pulley arrangement on the tower and led over another pulley installed near the arm's center of percussion. The cable end is attached to the lanyard retract system through a shear pin. A mechanical stop is swaged on the cable in a position that will allow its engagement with the arm after lanyard retraction is completed.

Calculations were made to determine actuator requirements for the S-II aft service arm. The cable was assumed to be attached near the arm center of percussion (390 inches from the center of rotation). The lead-in pulley was assumed to be mounted in the southeast corner 10 inches from the tower face and approximately 390 inches from the center of rotation. Cable travel and



NOTES:

1. CABLE TIES TO RELEASE AND WITHDRAWAL MECHANISM SO FIRST MOTION OF CABLE DOES NOT BEGIN ARM SWING UNTIL RELEASE AND WITHDRAWAL ALLOWS BUTTON TO BOTTOM ON STOP PLATE.
2. ARM RIGGING NOT SHOWN TO PERMIT CLARITY.
3. VEHICLE CONFIGURATION IS HYPOTHETICAL AND SHOWN FOR PURPOSE OF ILLUSTRATION ONLY.

Figure 7-24. Secondary Retraction System

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required tension were calculated to be 470 inches and 2190 pounds respectively. An 8 to 1 pulley arrangement has been proposed which would result in an actuator stroke of approximately 5 feet.

The mechanical efficiency of the cable/pulley system has been estimated to be about .65, thus yielding a required actuator thrust of 27,000 pounds. This thrust could be delivered by a pressure of 1700 psi acting against a 4.5-inch diameter piston. Reliability of the overall retraction system might be increased by the addition of a gravity powered back-up system (figure 7-4, item 12).

Hydraulic fluid is circulated in the secondary return loop by the rotary actuators as the secondary retraction system pulls the arm around. A lever which closes the cam valve in this loop is operated by engagement with an arm mounted on the secondary actuator piston rod. The pressure drop across the cam valve generated a retarding torque in the rotary actuators to decelerate the service arm.

A cable tension pressure regulator is connected in parallel with the secondary supply valve. This regulator maintains low pressure in the secondary actuator to prevent cable slack. It is recommended that the magnitude of this pressure be determined experimentally to assure smooth cable reeling when the primary system retracts the arm.

d. Access Arm Rotary Actuation.

Double cylinder piston-rack type rotary actuators are proposed to produce rotation of the access arms. Double-vane or multiple-vane actuators cannot be used for direct drive of the arms since the angle of rotation is large. Single-vane actuators could produce the necessary angular displacement but are relatively inefficient compared to the piston-rack units.

The criteria which govern actuator sizing are the wind loading conditions. Peak wind torque has been calculated to be 2,210,000 in.-lb. The application of this torque on the arm at initial retraction or remote extension demands that the actuation system be capable of producing an equal torque plus some additional magnitude of torque to begin and complete rotation within the specified amount of time. An interval of 30 seconds has been arbitrarily chosen as the time required for complete retraction. An access arm rotation angle of 180 degrees was assumed to simplify the dynamic calculations. The actual angle of retraction will be 198 degrees. The wind direction has been assumed constant for a full retraction cycle. The magnitude of the wind has been assumed to vary such that the applied wind torque will be a straight line function rather than sinusoidal. This assumption would lend a conservative analysis since the peak wind torque would have a maximum value at the critical starting and stopping of the arm.

This approach yields the following calculated system requirements: 2,300,000 in.-lb initial accelerating torque which is a straight line function to an equal final decelerating torque in 30 seconds producing a maximum angular velocity of .164 rad/sec at half of the full rotation angle. A commercially available off-the-shelf actuator to meet the above requirements has not been located. Vendor contact has indicated that an actuator can be designed and manufactured upon special order which would be rated above 1,200,000 in.-lb at 3000 psi. A pair of such actuators are proposed to furnish the torque for rotation of each access arm. The displacement constant for these units has been estimated at 460 $in.^3$/rad each. Thus, the volume requirements for retraction or extension of each arm would be about 12.5 gallons and the maximum flow rate would be 36 gpm. The purpose of the pressure compensating valves shown in the schematic is to eliminate the necessity of designing the actuator to withstand extreme pressure during deceleration. If a constant supply pressure of 3000 psi is assumed, the return pressure would approach 6000 psi during final deceleration in order to produce a net pressure of 3000 psi across the pistons. An ordinary high pressure hydraulic regulator modified for remote rather than downstream, control pressure pick-up would be adequate. The regulator would be set for some value above 3000 psi so that supply pressure would decrease as the return pressure tended to build up.

The net torque applied to the arm has a maximum value of 89,000 in.-lb. This means that only 89,000 in.-lb is sufficient to retract the arm when wind loading is not present.

A no-wind torque requirement of only about 4 percent of the full wind torque requirement presents a significant actuator control problem. This problem is further complicated by considering application of the full wind torque to accelerate the arm at the beginning of the retraction. The schematic depicts a relatively simple control system which would provide minimum control to compensate for the simplified wind conditions assumed.

Since the cam valve would be programmed for a maximum retarding wind, the other components of the control system would not function under this condition. Under a no-wind condition, the arm would accelerate almost immediately to the maximum angular velocity at which point the flow control valve would cut in. The pressure drop across the flow control valve is proportional to the applied wind torque, consequently, the arm ceases to accelerate. The angular velocity is held constant until the flow control valve opens again. Opening of the flow control closes a switch to energize the bypass solenoid valve. This valve opens and throws an additional orifice in parallel with the cam valve. The pressure drop across the cam valve is decreased and the arm slowly decelerates to the fully retracted

position.

The control system described above is not adequate for wind loading which varies radically in magnitude and/or direction during the rotation cycle. A more sophisticated control system would be needed to handle rapidly varying wind loading. One possibility would be a servo system employing a feed-back signal proportional to arm angular velocity. This signal would be fed to an error detector which would, in turn, operate a motor driven valve in the hydraulic return line. Thus, angular velocity as a function of angular displacement could be programmed as desired.

e. Latch Valves.

Several latch type double solenoid valves are shown on each of the fluid schematics. These are two-way, two-position valves which are mechanically latched and/or spring loaded to the position to which they were last energized. For example, assuming the valve to be latched closed; if the current through the solenoid which closed the valve is removed, the valve remains closed. The only method of opening the valve is to supply current to the other solenoid. After the opening solenoid is energized, inadvertent opening of either power circuit will not allow the valve to close.

An off-the-shelf source for this valve has not been discovered. At least one valve manufacturer has indicated an interest in

supplying these valves on special order. It is felt that the increase in system reliability fully justifies the additional cost of special procurement.

M. OPERATIONAL SEQUENCE

The following paragraphs present the manual and automatic operating sequences for the inflight retractable service arm, prelaunch retractable service arm, and access arm. Automatic sequences are presented in order of their occurance and are intended to bestow a general knowledge of the automation inherent to these arms, while each manual sequence is numbered and presented in a separate and independent paragraph.

The abbreviation ILCC following manual sequences indicates that these steps are performed manually from the Independent Launch Control Center.

1. Inflight Retractable Service Arm. (See figures 7-25 and 7-26.)

Sequences enclosed by parentheses are not applicable when inflight retraction is accomplished in conjunction with prelaunch retraction, but are to be incorporated when prelaunch retraction is omitted.

a. Automatic Primary Retraction.

The programmer energizes the lock-pin retract valve prior to engine ignition.

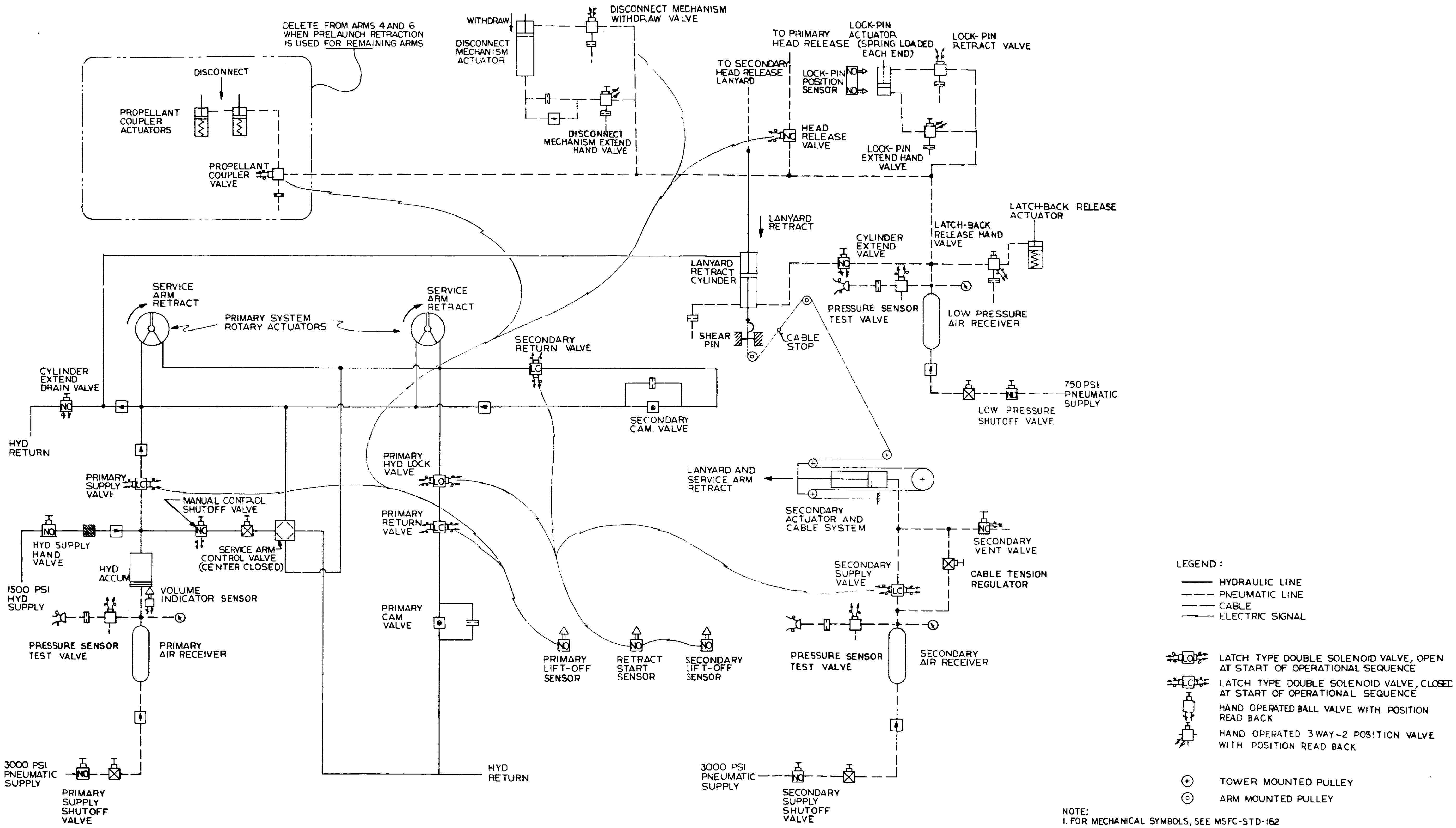

Figure 7-25. Inflight Service Arm Fluid Schematic

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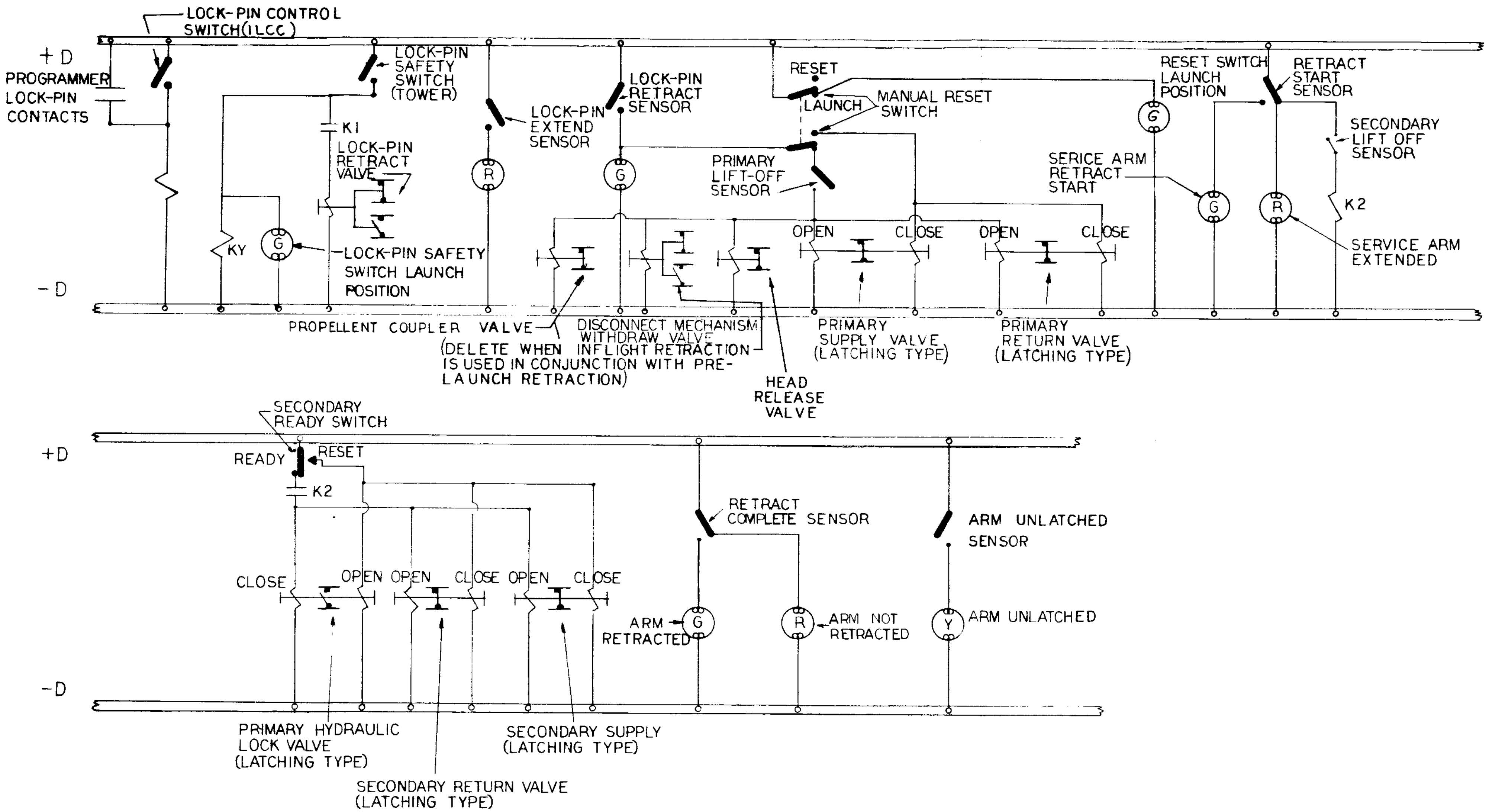

1. FOR ELECTRICAL AND ELECTRONIC SYMBOLS, SEE NASA STD. DWG. NO. A10443376

Figure 7-26. Inflight Service Arm Electrical Schematic

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Pneumatic pressure is then applied to the retract side of the lock-pin actuator thereby disengaging the lock-pin. The lock-pin retract sensor confirms the lock-pin retraction and arms the primary lift-off sensor.

Initial vehicle motion closes the primary lift-off sensor and opens the primary supply, primary return, and head release valves. Pneumatic pressure operates the head release lock-pin and the head is consequentially ejected.

(The propellant coupler valve is energized causing pneumatic pressure to be applied to the propellant coupler actuators, thereby disconnecting the couplers. The disconnect mechanism withdraw valve is energized causing pneumatic pressure to be applied to the withdraw side of the disconnect mechanism actuator. The disconnect mechanism is now withdrawn.)

Hydraulic pressure is applied to the rotary actuators and lanyard retract cylinder. Initial lanyard retraction operates the head release lock-pin, if the primary head release has failed. The lanyard will continue to full retraction. Tension is maintained on the cable by a low pressure supply to the secondary actuator and a shear pin at the arm. The arm begins rotation due to torque applied by the rotary actuators. At this time, the retract-start sensor opens to prevent a secondary system operation. As the arm approaches

approximately half of the full retraction angle, a cam operated valve in the primary return line begins closing to decelerate the arm. When the arm completes its rotation, it will be mechanically latched in the retracted position, thereby closing the retract-complete sensor.

b. Automatic Secondary Retraction.

If a malfunction of the primary retraction system occurs, the arm will not rotate and the retract-start sensor will remain closed. Immediately upon vehicle motion, the primary lift-off sensor is closed and at a predetermined vehicle travel distance, the secondary lift-off sensor is closed. This completes the circuit through the retract-start sensor and originates the operation of the secondary system. The secondary supply and secondary return valves are latched open and the primary hydraulic-lock valve is latched closed. Pneumatic pressure is now applied to the secondary linear actuator. Initial action of the secondary linear actuator shears a pin and operates the lanyard retract cylinder, then the cable-stop engages the umbilical arm. Torque is applied through the cable system and the arm begins its rotation. As the arm approaches approximately half of the full retraction angle, the secondary actuator piston rod engages the secondary cam-valve lever. The secondary cam-valve then begins closing to decelerate the arm. When the arm completes its rotation, it will be mechanically latched in the retracted position, thereby closing the retract-complete sensor.

c. Manual Extension.

(1) Place manual reset switch to reset position.

This action causes the primary supply and primary return valves to be latched closed, the head release valve to close, and the propellant coupler valve to be de-energized. The disconnect mechanism withdraw valve will also close at this time.

(2) Close secondary supply shut-off valve.

(3) Open secondary vent hand valve.

(4) Open manual control shut-off valve.

(5) Open latch-back release hand valve.

This action causes pneumatic pressure to be applied to the latch-back release actuator. The latch-back mechanism is disengaged, thereby closing the arm unlatched sensor.

(6) Place service arm control valve in extend position and hold until arm is fully extended.

This action causes hydraulic pressure to be applied to the extend side of the rotary actuators. Hydraulic return from the retract side of the rotary actuators passes through the arm control valve. The service arm now begins its rotation. The cable system pulls the secondary actuator toward the extend position, while pneumatic back-pressure in the secondary actuator is vented through

the secondary vent hand valve. The retract-start sensor will now close.

(7) Open lock-pin safety switch.

(8) Open lock-pin extend hand valve.

The lock-pin retract valve is de-energized which vents the retract side of the lock-pin actuator. Pneumatic pressure is then applied to the extend side of the lock-pin actuator causing the lock-pin to engage the arm. If the lock-pin does not seat properly, the service arm control valve should be alternately placed in the retract and extend positions until the lock-pin is seated. The lock-pin extend sensor will confirm full engagement of the lock-pin.

(9) (Open disconnect mechanism extend hand valve.)

(Pneumatic pressure is now applied to the extend side of the disconnect mechanism actuator and the disconnect mechanism extends.)

(10) Close secondary vent hand valve.

(11) Open secondary supply shut-off valve.

(12) Open cylinder extend-drain valve.

(13) Open cylinder extend valve.

Pneumatic pressure is now applied to the extend side of the lanyard cylinder. As the cylinder extends, hydraulic fluid is forced from the retract side of the cylinder.

2. <u>Prelaunch Retractable Service Arm.</u> (See figures 7-27 and 7-28.)

a. Automatic Primary Retraction.

The programmer energizes the lock-pin retract valve prior to engine ignition causing pneumatic pressure to be applied to the retract side of the lock-pin actuator and thereby disengaging the lock-pin. The lock-pin retract sensor will confirm the lock-pin retraction and arm the thrust-commit contacts. The thrust-commit contacts close upon engine confirmation. The primary supply valve is now latched open, also head release and propellant coupler valves are opened. Pneumatic pressure causes the head release lock-pin to release the head, which is ejected, thereby closing the head release sensor. Pneumatic pressure will be applied to the propellant coupler actuators, releasing the propellant lines and closing the coupler release sensor. Hydraulic pressure is applied to the lanyard retract cylinder. Initial lanyard retraction will operate the head-release lock-pin if the primary head-release has failed. The lanyard will continue to the full retracted position. Tension will be maintained on the cable by a low-pressure supply to the secondary actuator. Closing of the head-release sensor and coupler-release sensor completes the circuit and energizes the disconnect mechanism withdraw valve.

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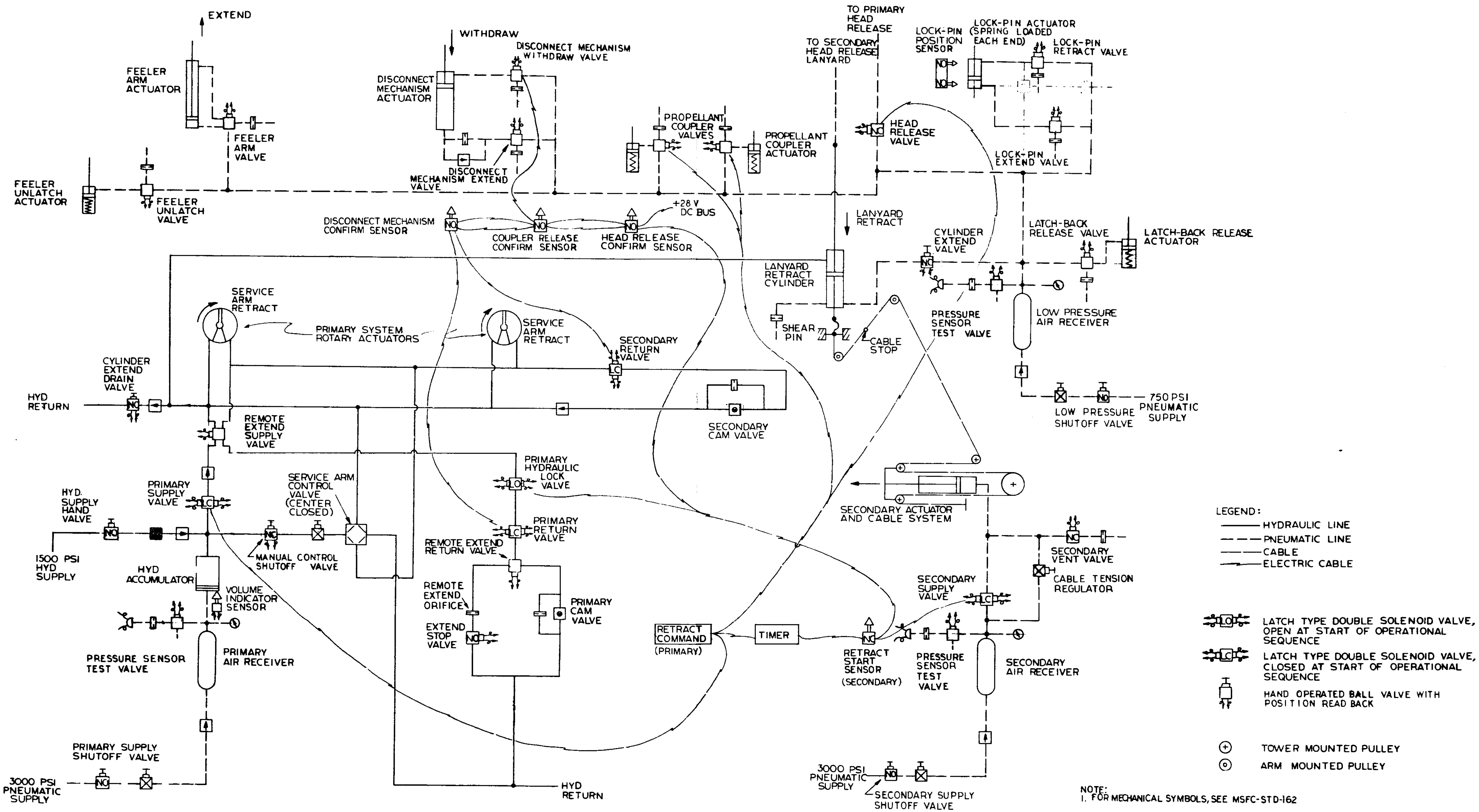

Figure 7-27. Prelaunch Service Arm Fluid Schematic

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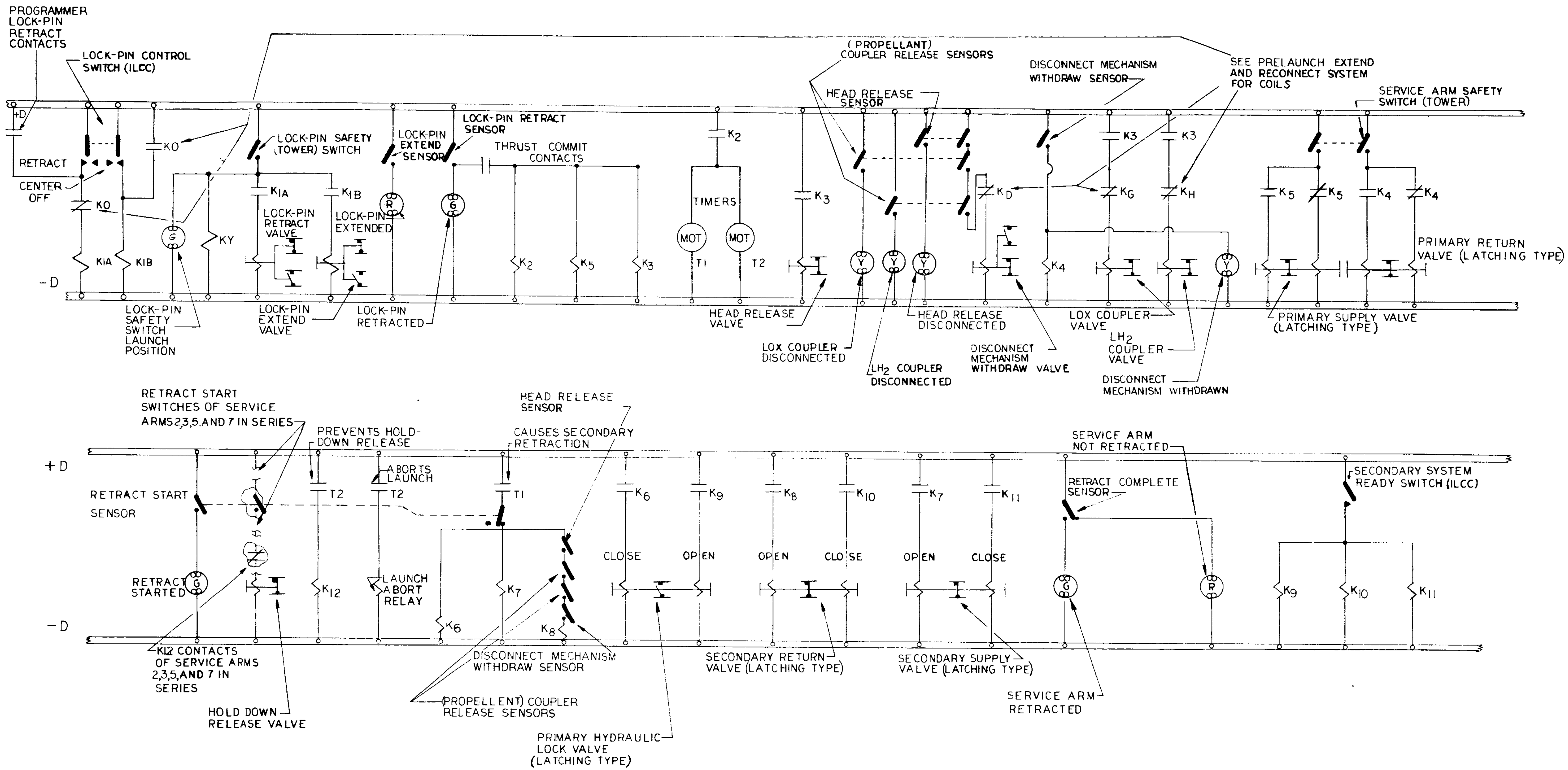

1. FOR ELECTRICAL AND ELECTRONIC SYMBOLS, SEE NASA STD. DWG. NO. A10443376

Figure 7-28. Prelaunch Service Arm Electrical Schematic (Retraction)

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Pneumatic pressure is then applied to the disconnect mechanism actuator, withdrawing the disconnect mechanism. The disconnect mechanism withdraw sensor closes at this point, completing the circuit to latch open the primary return valve, thereby allowing operation of the rotary actuators. Due to torque applied by the rotary actuators, the service arm begins its rotation. The retract-start sensor will now open to prevent secondary system operation. As the arm approaches approximately half of the full retraction angle, a cam operated valve in the primary return line begins to close to decelerate the arm. When the arm completes its rotation, it will be mechanically latched in the retracted position thereby closing the retract-complete sensor.

b. Automatic Secondary Retraction.

If a malfunction of the primary retraction system occurs, the service arm will not rotate and the retract-start sensor will remain closed. Upon original thrust-commit contact closure, a control timer was energized. The timer contacts will close at a predetermined time interval, completing the circuit through the closed retract-start sensor. This action energizes the secondary supply valve and primary hydraulic lock valve. This action also energizes the secondary return valve through the head release sensor, coupler release sensor, and disconnect mechanism withdraw sensors. The secondary supply and secondary return valves are latched open and

the primary hydraulic lock valve is latched closed. Pneumatic pressure is applied to the secondary linear actuator. Initial action of the secondary linear actuator operates the lanyard retract cylinder, causing the cable-stop to engage the service arm. The service arm now begins its rotation due to torque applied through the cable system. As the arm approaches approximately half of its full retraction angle, the secondary actuator pistor rod engages the secondary cam-valve lever. The secondary cam-valve then begins closing to decelerate the arm. When the arm completes its rotation, it will be mechanically latched in the retracted position thereby closing the retract-complete sensor.

c. Remote Extend and Reconnect. (See figure 7-29.)

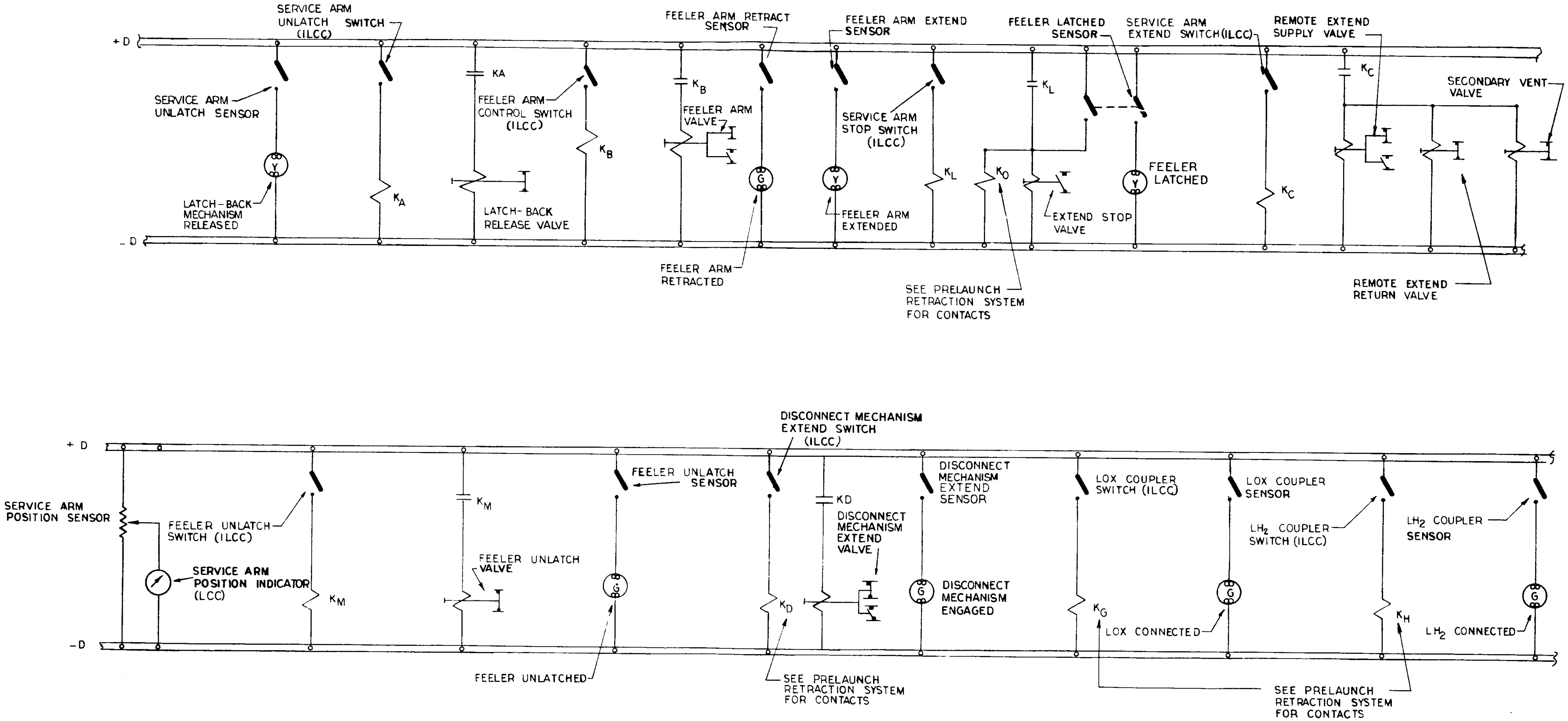
Remote extend and reconnect can be accomplished only if retraction was obtained by the primary system.

(1) Close service arm unlatch switch. (ILCC)

This action energizes the latch-back release valve. Pneumatic pressure is then applied to the actuator, disengaging the latch-back mechanism and closing the service arm unlatch sensor.

(2) Close service arm extend switch. (ILCC)

The remote-extend supply valve, remote-extend return valve, and secondary vent valve are now energized. Hydraulic pressure is applied to the extend sides of the rotary actuators.



1. FOR ELECTRICAL AND ELECTRONIC SYMBOLS, SEE NASA STD. DWG. NO. A10443376

Figure 7-29. Prelaunch Service Arm Electrical Schematic (Extend and Reconnect)

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The hydraulic primary return flow is routed through the remote extend orifice to limit the service arm angular velocity. The arm rotation begins causing the cable system to pull the secondary actuator toward the extend position. Pneumatic back pressure in the secondary actuator is then vented through the secondary vent valve.

(3) Close service arm stop switch when service arm is in proper relative position to vehicle as indicated by service arm position indicator. (ILCC)

The extend-stop valve is now energized to the closed position, causing arm rotation to stop.

(4) Close feeler arm control switch. (ILCC)

See Appendix A for principles of reconnect mechanism.

The feeler arm valve is energized. Pneumatic pressure is applied to the extend side of the feeler arm actuator and the retract side is vented. The feeler arm will extend (Appendix A, figure IV) and close the feeler arm extend sensor.

(5) Open service arm stop switch. (ILCC)

The extend-stop valve is now de-energized. The extend-stop valve will open and the service arm will resume rotation. The feeler arm "chase" begins when the feeler arm rollers contact the vehicle and continues until the vertical tee-bar on the vehicle is contacted (Appendix A, figure IV). At this time, the mechanism which latches the feeler arm to the vertical tee-bar is actuated and the

feeler-latched sensor closes. This action causes the extend-stop valve to be energized, the lock-pin retract valve to be de-energized, and the lock-pin extend valve to be energized. The extend-stop valve is closed. The arm will now stop all motion and become hydraulically locked. Pneumatic pressure is applied to the extend side of the lock-pin actuator and the lock-pin will engage the service arm. At this point, the lock-pin extend sensor will close to confirm the lock-pin engagement.

(6) Close disconnect mechanism extend switch. (ILCC)

The disconnect mechanism withdraw valve is now de-energized, and the disconnect mechanism extend valve is energized. Pneumatic pressure is applied to the extend side of the disconnect mechanism actuator through an orifice which reduces the speed of actuation. The disconnect mechanism will begin to extend. The vertical "chase" will start when the rollers contact the vehicle and continue until the extendable coupler end is guided into place by the vee, (Appendix A, figure V). This vee straddles the vehicle half of the propellant coupler. Upon completion of these procedures, the disconnect mechanism extend sensor will close to confirm engagement.

(7) Close propellant coupler switches. (ILCC)

The propellant coupler valves are now de-energized. The pneumatic pressure is vented from the propellant coupler actuator to permit the spring force to provide the final coupling action,

(Appendix A, figure V). The propellant coupler sensor (LH_2 and LOX) will close to confirm coupling.

(8) Close feeler-unlatch switch. (ILCC)

The feeler-unlatch valve is now energized and subsequently opens. Pneumatic pressure will be applied to the feeler-unlatch actuator which unlatches the feeler causing the feeler-unlatch sensor to close.

(9) Open feeler arm control switch. (ILCC)

The feeler arm valve is now de-energized. Pneumatic pressure will be applied to the retract side of the feeler arm actuator and the extend side will be vented. The feeler arm will retract, causing the feeler arm retract sensor to close. The system is now ready for propellant drain procedures.

d. Manual Extension.

The operational sequence for manual extension of the prelaunch system is similar to the sequence described for the in-flight system. The only significant difference between the two systems is the origin of the electrical signals. (See figures 7-26 and 7-29.)

3. <u>Access Arm.</u>

a. Remote Retract. (See figures 7-30 and 7-31.)

(1) Close ring unlatch switch. (ILCC)

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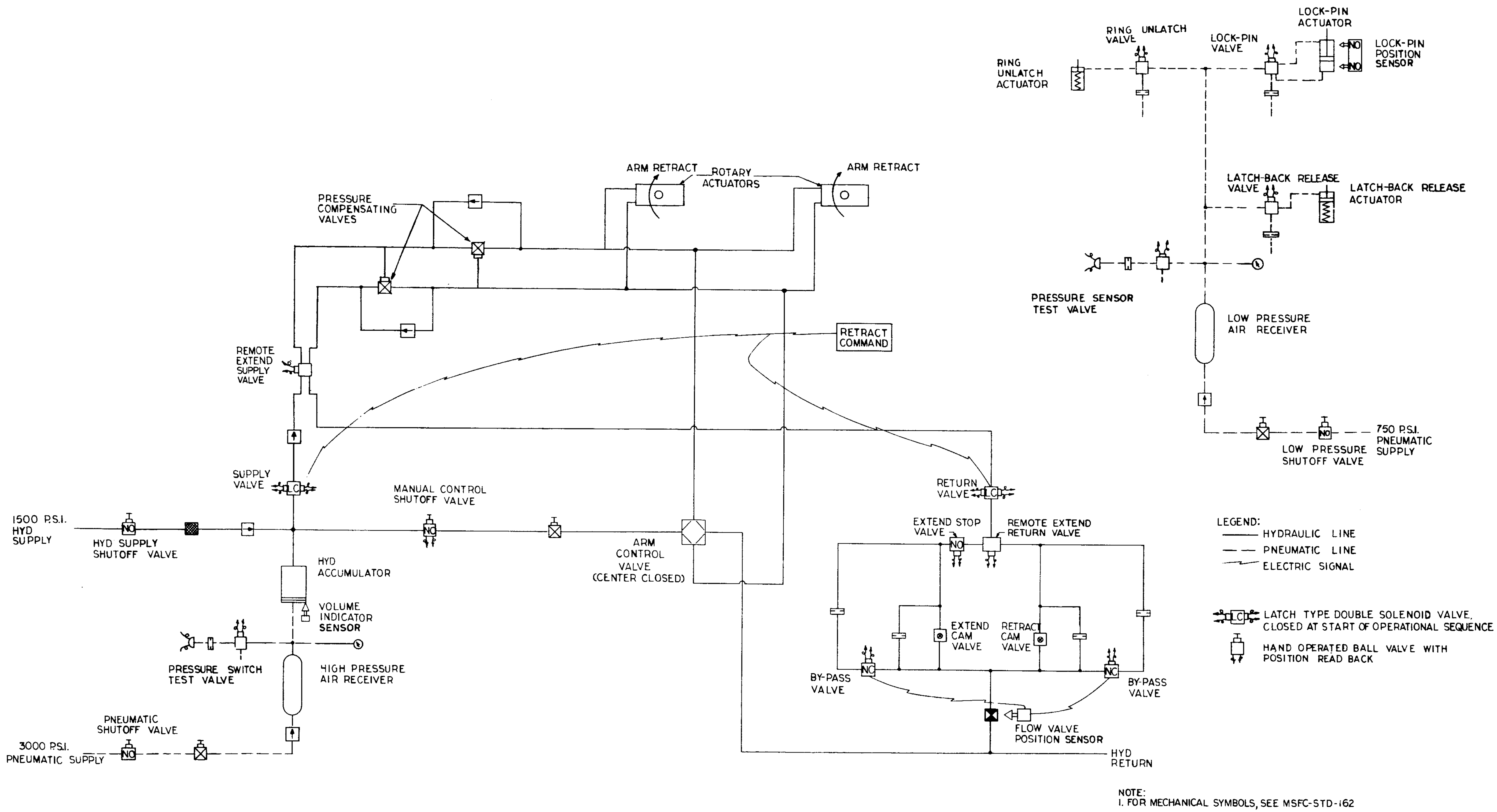

Figure 7-30. Apollo Access Arm Fluid Schematic

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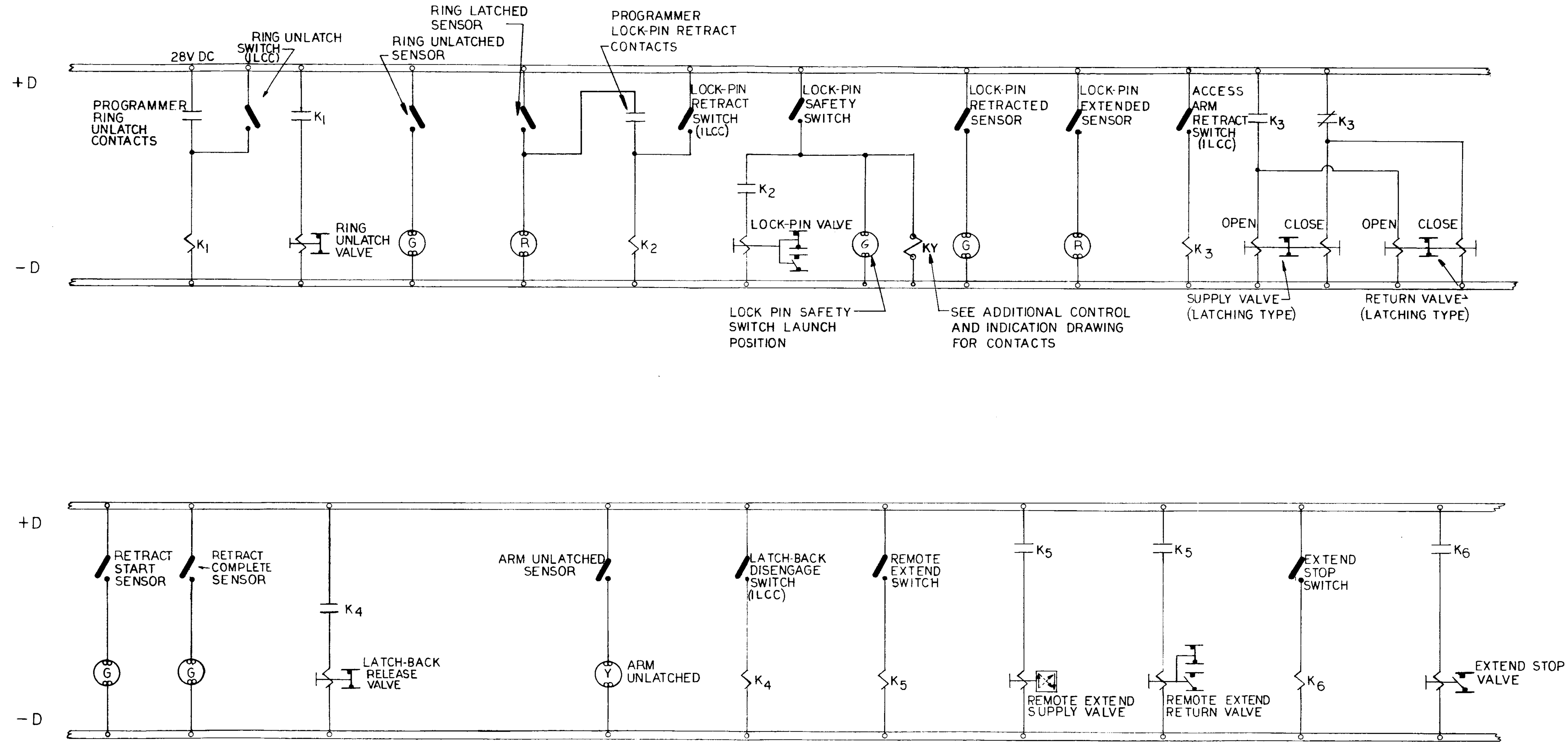

1. FOR ELECTRICAL AND ELECTRONIC SYMBOLS, SEE NASA STD. DWG. NO. A10443376

Figure 7-31. Apollo Access Arm Electrical Schematic

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The ring unlatch-valve is now energized causing pneumatic pressure to be applied to the ring unlatch actuator. The arms are subsequently unlatched which is evidenced by the ring unlatched sensor.

(2) Close lock-pin retract switch. (ILCC)

The lock-pin valve is now energized, causing pneumatic pressure to be applied to the retract side of the lock-pin actuator. The lock-pin retracts, closing the lock-pin retracted sensor.

(3) Close access arm retract switch. (ILCC)

The supply and return valves are latched open, causing hydraulic pressure to be applied to the rotary actuators. The access arm will now begin its rotation due to torque applied by the rotary actuators. The retract-start sensor closes. When the arm completes its rotation, it will be mechanically latched in the retracted position thereby closing the retract-complete sensor.

b. Remote Extend.

(1) Open ring unlatch switch.

The ring unlatch extend valve is now de-energized and pneumatic pressure will be vented from the ring unlatch actuator.

(2) Close latch-back disengage switch. (ILCC)

The latch-back release valve is now energized. Pneumatic pressure is applied to the actuator in order to disengage

the latch-back mechanism, closing the arm unlatched sensor.

(3) Close remote-extend switch.

The remote-extend supply and remote-extend return valves are now energized. Hydraulic pressure is applied to the extend side of the rotary actuators, causing the access arm to begin its rotation. When the access arm completes its rotation, the arms are mechanically latched together, closing the ring-latched sensor.

NOTE

An emergency stop of the arm can be made using the extend-stop switch, which closes the extend-stop valve.

N. TRANSPORT TRAILER

Handling and transport of the umbilical arms at the fabrication plant, in transit, and at the launch site will be accomplished by means of a special trailer (figure 7-32). The trailer should permit ready access for installing or checking equipment on the arm, and should be designed to permit handling the arms over normal hard-surfaced roads. Tarpaulins or other coverings may be used to protect the arms and equipment in transit or storage.

Construction of the trailer should be as conventional as possible, and standard parts such as axles, wheels, and bogies should be used, with due regard to the shock limitations of the arm.

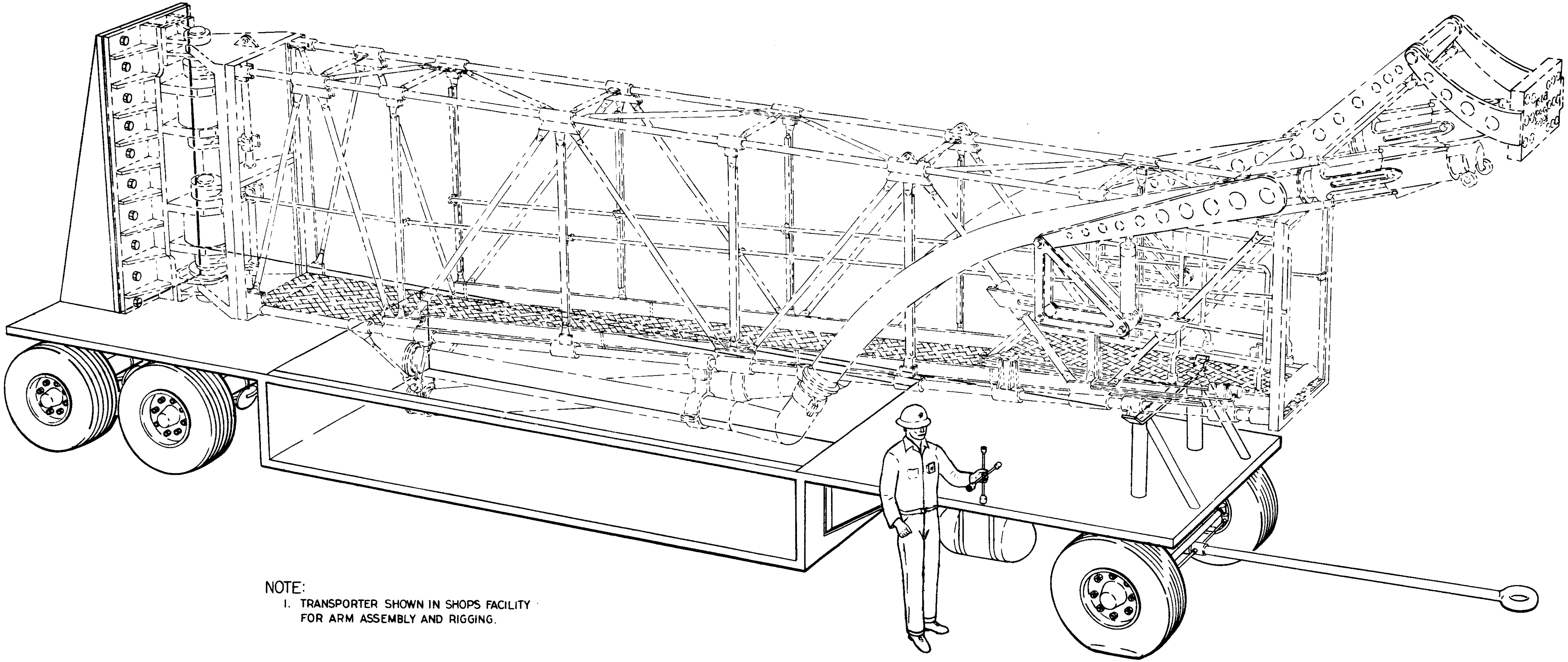

Figure 7-32. Transport Trailer

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Because the access arms which service the Apollo spacecraft are considerably bulkier than the service arms, it may be desirable to transport these access arms in two sections. The access arms then would undergo final assembly at the tower construction site. The straight portion would contain basically all of the special equipment and lines for umbilical supply. The curved portion, of semicircular shape, would be attached at final assembly using prefitted or gauged connections.

SECTION VIII

UMBILICAL TOWER REQUIREMENTS

A. OVERALL CONFIGURATION

The basic configuration of the C-5 transporter-launcher consists of a movable platform which carries the flight vehicle and the umbilical tower. The platform may be transported either as a floatable barge or as a tractor-crawler. All umbilical connections are secured and checked out in the VAB. Maintenance and checkout of the tower and vehicle is performed in the vertical assembly building (VAB), before transportation to the launch pad for propellant loading, final checkout, , and launching.

For convenience and economy, a four-cornered tower design, on centerline north of the vehicle and with its face vertical and square with a normal from the vehicle, is contemplated. The tower is constructed of structural steel with a base of approximately 60 feet by 60 feet, and is tapered on two sides to the 250-foot level. From this point upward, three sides are vertical. The general configuration is shown in figure 5-1.

B. LOADS

Wind loadings on the tower are shown in figures 6-6 and 6-7. These figures indicate wind loading that may be expected during the

strongest wind month. Tower deflection on the launch pad may need to be restricted to a maximum value. See figure 6-9 for deflections of an assumed umbilical tower.

C. TOWER DECKS

Tower decks will be required in the approximate vicinity of expected arm locations to support control consoles and equipment and provide personnel access to the arms.

D. UMBILICAL ARM SERVICE AND UTILITY REQUIREMENTS BY LOCATION

Provision shall be made at each arm level for 110/220-volt electrical outlets and 125 psi pneumatic tool supply for minor servicing and repairs to the vehicle or service arms at the launch site. Major repairs will be accomplished at the VAB. Any service requirements peculiar to a particular stage will be specified by the stage contractor.

E. CRANE

If lifting of the umbilical arms from the tower is contemplated, a tower crane with a capacity of 20,000 pounds must be provided.

F. SERVICE ELEVATOR

A service elevator shall be incorporated in the design of the umbilical tower and shall have capability as follows:

1. Carry a minimum of nine passengers.

2. Carry a cargo package of maximum size of six-foot cube and gross weight of one ton.

The elevator must be capable of being elevated to the highest tower deck.

G. SAFETY DEVICES

Reasonable design considerations shall be established to incorporate on the tower structure suitable safety measures for personnel working in the area during prelaunch activities. Safety measures shall include such items as:

1. Guard rails.
2. Safety belt hooks.
3. Slip-proof walkways and gratings.
4. First aid kits.
5. Eye wash and safety shower points.

SECTION IX

VERTICAL ASSEMBLY BUILDING REQUIREMENTS

The presently planned combinations of stages, covered by the C-5 vehicle designations, require many retractable arms for the support of umbilical services and for access to the vehicle. The locations of these arms are shown in figure 4-1. It must be assumed that evolution will result in many other combinations of arms which will be required during the useful life of Complex 39.

The vertical assembly building must be so designed that any combination of arms or arm spacing, which may be needed, can be accommodated without basic structural change.

Basic vertical assembly building criteria imposed by the umbilical arms are as follows:

(1) Umbilical arms may be required at any level from 50 feet to 370 feet above the launch deck.

(2) The capability must be provided for test release of all umbilical connections and retraction of the umbilical arms.

(3) Regardless of the type of umbilical arms which may be selected for presently projected configurations, provision should be made to allow the greatest possible freedom for the future use of the facility.

Should the proposed "open" vertical assembly building be

selected, it will be necessary that the doors be so designed to accommodate the variety of umbilical arm combinations.

SECTION X.

FULL SCALE TEST

A. PURPOSE OF TESTING

Each arm used to service the C-5 vehicle on the launch site will be subjected to a full scale functional test at MSFC test area before shipment to the Atlantic Missile Range. Presently invisioned operational requirements call for three complete transporter-launcher complexes with all necessary arms and spares. To insure maximum reliability and compliance with specifications, the first set of arms in the series, will be given comprehensive design evaluation tests. The two remaining sets of arms will be given production acceptance tests at MSFC. The design evaluation tests will determine adequacy of design and function, while the production acceptance tests are primarily intended for quality control assurance. The purposes of the tests are to:

1. Check out all electrical, pneumatic, and hydraulic systems including umbilical systems and their backups.

2. To check out primary and secondary retract systems.

3. To substantiate design criteria, determine necessary modifications and retest after modifications have been accomplished.

4. To pinpoint and eliminate all trouble areas before arms are shipped to Cape Canaveral.

5. To check out remote reconnect mechanisms, if applicable.

B. TEST SITE (MSFC)

The test site will be divided into two separate areas as shown in figure 10-1. For clarity they will be referred to as area "A" and area "B". Area "A" will consist of two vehicle simulators and eight service arm supports. At two service arm support locations, structure must be provided for mounting an Apollo access arm pair above the service arm. In this area, all hardware will be received, inspected, and assembled. All tests will be performed here, with the exception of tests involving the pumping of fuel and LOX, and tests involving simulated horizontal vehicle and tower motions. All pneumatic, hydraulic and electrical primary, and secondary systems with their associated backup systems must be provided in this area. There must also be provided necessary structure at each arm support for the mounting of the secondary arm retract mechanism. Provisions must be made for simulating wind loads on the arms during retraction tests. Facilities for the testing and recording of data must also be provided. The vehicle simulator which is to be used in this area must be designed with the capability of producing up to 1.5 g acceleration (0.5 Net) in the vertical direction with vehicle plates and associated equipment attached.

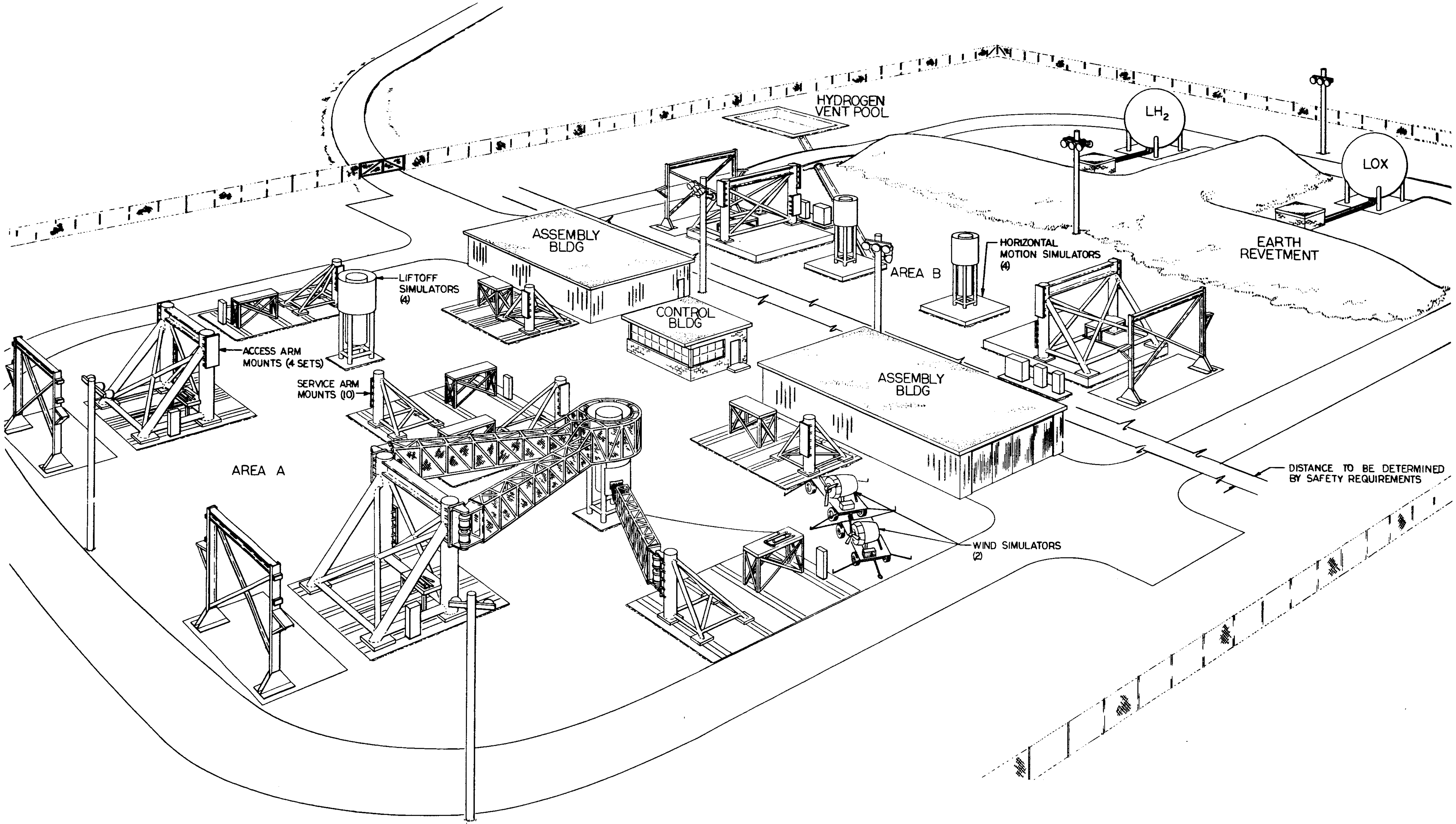

Figure 10-1. Umbilical Arm Test Site

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Provisions must be made to simulate vehicle length variation of +3 inches for temperature and -7 inches for settling with propellant loading. The support beams provided for mounting the service and access arm must exactly duplicate the vertical mounting column of the transporter-launcher tower. In this way, it will be assured that arms and associated equipment which have been mounted and tested at the test site will be compatible with the transporter-launcher tower at the Cape. This area must be capable of testing the eight service arms and the two sets of access arms simultaneously, if desired. An assembly and equipment maintenance building will also be provided in this area.

Area "B" will be equipped with two vehicle simulators and two service arm supports. All wet tests, and vehicle and tower horizontal motion tests will be conducted in this area. The area must have the capability of simulating rainfall to check fuel and LOX disconnect operation under heavy icing conditions. The vehicle simulator used in this area must be designed with the capability of simulating vehicle length variation with temperature changes and vehicle tanking, and of producing a random lateral motion of 4 to 40 inches, at a frequency ranging from 0.20 to 0.90 cps. These ranges will cover the frequencies and amplitudes of the vehicle motion from lower arm station to the upper arm station. The simulator must also be capable of

accelerating the vehicle plates and associated equipment in a vertical direction up to 1.4 g (0.4 g Net). Total accelerated vertical travel of the simulator will be at least 10 feet. The service and access arm supports must be capable of producing a random lateral motion of 1/4 inch to 24 inches displacement at a frequency of 1.33 cps or less to test arm and arm mounted equipment.

Storage and pumping facilities must be provided for fuel and LOX with a pressure capability of 150 psi and a flow rate of 500 gpm. Means of venting and disposing of LH_2 must also be available and vent lines must be capable of taking pressure up to 40 psi. As in area "A", all pneumatic, hydraulic, and electrical systems, both primary and secondary, must be provided in addition to the primary and secondary retract mechanism.

C. OPERATION

1. Hardware.

All electrical, pneumatic, hydraulic, and mechanical hardware used in the service and access arm tests will be exactly that which will be used for launches at the Atlantic Missile Range.

2. Primary System.

The primary system of the service and access arms must be operated and tested under full scale test conditions. Malfunctions must be injected in these systems to cause the backup systems to

take over and perform their function.

3. Malfunction Inject.

The wiring and plumbing for all systems shall be designed such that malfunction of any kind may be injected as desired. This will make it possible to check out the backup systems under simulated failures.

4. Backups.

All backup systems for the mechanical, pneumatic, hydraulic, and electric systems will be installed and connected for tests. The primary and secondary retract systems will be tested under various conditions of malfunction.

5. Instrumentation Required.

Instrumentation must be provided for taking and recording the following data:

a. LOX Pressure.

b. LH_2 Pressure.

c. Fluid flow and pressure at various points in the hydraulic systems.

d. Torque and other forces developed by primary and secondary retract mechanisms.

e. Stresses developed in various parts of arm structures.

f. Angular and linear accelerations of service and access

arms.

g. Random motion (amplitude and frequency).

h. Temperature of various components during wet tests.

i. Sequence timing.

j. Wind velocities and direction.

6. Fluid Handling Capabilities.

The LOX and LH_2 pumping facility must be capable of 150 psi pressure; however, full scale flow will not be attempted in the test area. Where it is necessary, orifices will be used downstream of the equipment being tested to maintain operating pressure. A line must be provided to carry venting hydrogen to a remote disposal system. LOX vapor will be vented to the atmosphere in the usual manner.

7. Pneumatic Supply.

Supply of pressurized helium, nitrogen, and gaseous hydrogen must be provided at the test site for the operation of the various systems involved in the service and access arm tests.

8. Electrical Supply.

All electrical service which is required at the umbilical arms for the check-out and launch of a vehicle must be provided at the test site. Full scale electrical hardware will be used on all tests. Any umbilical connections which are energized at disconnect during a full-scale launch, must be energized at disconnect during service arm

tests at the test site. They must be energized such that the same voltage and current as during a full-scale launch, is developed.

9. Scheduling of Test Area Construction.

Scheduling time for the design and construction of the test area and test equipment is covered in Section XI.

10. Test Operations Programs.

a. Tests Required - General.

All systems will be ultimately tested for performance under simulated launch conditions. Data will be taken on primary and backup system response. Timing and g-load measurements must be taken for arm retraction. Stress levels must be recorded in various areas of service and access arm structure, which will require strain gages and their associated circuitry and recording equipment. Pneumatic and hydraulic pressures must be determined for optimum operation of access and service arms.

b. Test Desired - Specific.

(1) Release Connectors.

(a) Release of couplings should be tested with both the primary and backup systems.

(b) They should be tested under the conditions of vehicle and tower motion.

(c) Tests should be made after the pumping of

LOX and LH_2 to check performance at low temperature.

(d) Tests should be made during icing conditions after LOX and LH_2 have been pumped during simulated rainfall.

(2) Withdrawal Mechanism. (These items are the same as C. 10. b. (1).

(3) Arm Retraction Mechanism.

Arm retraction must be tested with both primary and backup systems. Functional tests of primary and secondary retract systems will be conducted separately. After successful tests of each system, secondary systems will be functionally tested by introducing malfunctions in primary systems. Simulated wind loads must be imposed on arms during retraction tests.

(4) Order of Tests.

(a) Function of connector release with primary and backup systems.

(b) Function of umbilical withdraw mechanisms with primary and backup systems.

(c) Arm retraction with primary and secondary systems.

(d) Function of connector release, withdrawal, and arm retraction.

(e) Wet test vehicle connectors.

(f) Disconnect after wet test with primary and backup systems.

(g) Disconnect, withdrawal, and arm retraction after wet test.

(h) Simulated lift-off, disconnect, and withdrawal.

(i) Simulated lift-off, disconnect, withdrawal, and arm retract.

(j) Simulated lift-off, disconnect, withdrawal, and retract with secondary retract mechanism the only functioning arm system.

(k) Wet test, lift-off, disconnect, withdrawal, and arm retract.

(l) The above order of tests will be performed under the condition of simulated vehicle and tower lateral motion.

(m) In the event remote reconnect of propellant loading devices is required, facilities will be flexible in design so that test of this function can be performed under simulated launch-abort conditions.

(5) Countdown.

The control building must have adequate equipment for manual and automatic countdown and sequencing of arm tests.

11. Overall Test Schedule.

The overall test program for the first set of arms must be completed within the time periods under Section XI.

SECTION XI

DEVELOPMENT AND TIME REQUIREMENTS

Figure 11-1 is a bar graph showing development of the umbilical arms beginning with criteria and design studies and ending with their checkout on Complex 39. This schedule is based upon having operational arms ready for use on transporter-launcher 2 (TL 2) for use with the facility checkout vehicle on March 15, 1965.

Preliminary studies included in this report began in May, 1962, and ended August 1, 1962. Other phases of criteria and design studies will continue through October 31, 1962. This report forms a basis for subsequent design of the umbilical arms, and establishes arm requirements for those related structures, namely the umbilical tower, the transporter-launcher, and the VAB, so that their design might proceed concurrently.

Initial design of the umbilical arms must be accomplished in 10 months ending June 1, 1963, if the above stated availability is to become an actuality. Development of a test site and design of the testing facilities should be contracted, constructed, and the equipment checked out by April 15, 1964. Contract award and fabrication should begin on the first set of umbilical arms (for TL 2) by September 15, 1963, with a follow-on of additional arm sets. As fabrication is completed on each of the arms, they would be transported to the test site. Firing

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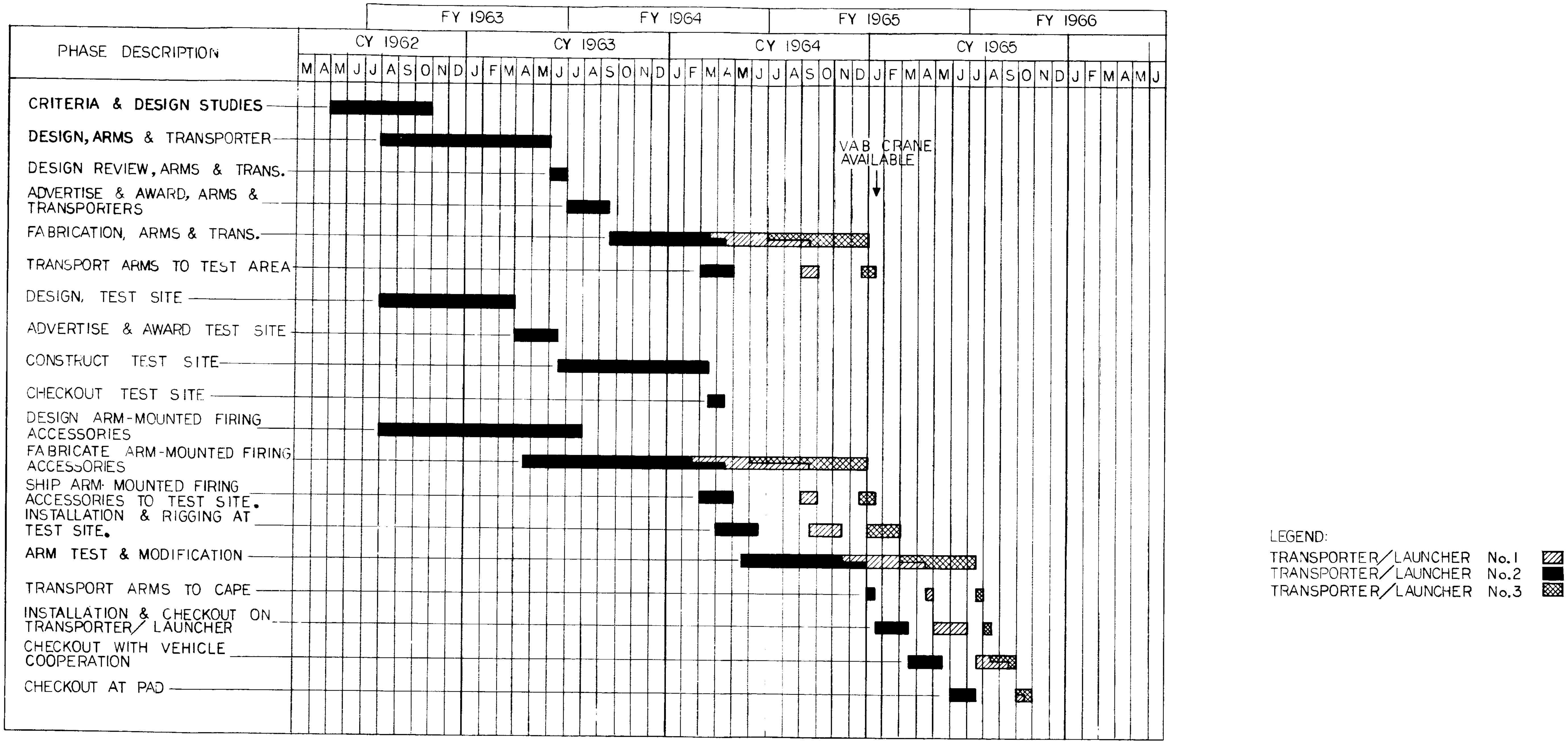

Figure 11-1. Development of Umbilical Arms

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accessories to mount on the arms will arrive at the test site concurrently with the arms. The first umbilical arm installation and rigging on the test site should begin no later than April 1, 1964, with actual testing beginning on May 15, 1964. Testing of each umbilical arm and appurtenances will be required prior to delivery to the Cape. Any modifications to the arms and/or to the rigging would be done on the test pad. These changes would be incorporated on the design drawings so that subsequent sets of arms fabricated would reflect the latest modification possible.

When testing of the arms is complete, they would be transported to Cape Canaveral where final checkout with the vehicle is accomplished.

Time and probably money could be saved in the basic umbilical arm by use of a design and manufacturing contract in which no intervening advertising and award interval would be required, and some overlap between design and manufacturing can be allowed.

SECTION XII

COST ESTIMATES

Basic Service Arm Assembly

Costs for basic components of the umbilical arms are determined in a conventional manner. From the parts list for each assembly, a cost estimate is made for every commercially available part and for raw material, using standard stock sizes. Engineering estimates are made of man-hours to perform the elementary shop operations to form the components and to assemble them into the final assembly. Inspection time, checking, rework, etc., are included to complete the total labor man-hours.

Labor hours are multiplied by an average wage rate to obtain total labor costs.

Estimates on material were made and included in the gross cost of each component.

Figure 12-1 shows a chart tabulating the estimated unit costs and the total cost for the first set of umbilical arms. Where possible a cost breakdown was made indicating the material, labor, and profit. The calculations appear in the respective appendices. A profit and contingency percentage of ten percent was used.

COST ESTIMATE C-5 UMBILICAL ARMS

ITEM	UNIT COST	No	TOTAL COST
SERVICE ARM			
TRUSS ASSEMBLY	14,800	7	103,600
EXTENSION PANEL	1,600	3	4800
EXTENSION PLATFORM	6,000	7	42,000
SERVICE PLATFORM, BUMPER LATCHBACK, AUX. SUPPORT	1,000	7	7,000
CONTROL PANEL, ACTUATING ASSEMBLY, HYDROLICS & PNEUMATICS	45,700	7	319,900
UMBILICAL HOUSINGS (PLATE) 2 EACH	24,000	6	144,000
DISCONNECT MECHANISM	12,000	6	72,000
ELECTRICAL CONTROL	16,000	7	112,000
No 1 RIGGING ASSEMBLY	—	1	—
No 2 RIGGING ASSEMBLY	30,000	1	30000
No 3 RIGGING ASSEMBLY	20,000	1	20000
No 4 RIGGING ASSEMBLY	20,000	1	20000
No 5 RIGGING ASSEMBLY	30,000	1	30000
No 6 RIGGING ASSEMBLY	30,000	1	30000
No 7 RIGGING ASSEMBLY	20,000	1	20000
ACCESS ARM (PER PAIR)			
TRUSS ASSEMBLY	65,000	2	130,000
SERVICE PLATFORM, BUMPER, LATCHBACK AUX SUPPORT	2000	2	4000
MOVABLE STANDS	6000	2	12,000
CONTROL PANEL, ACTUATING ASSEMBLY, HYD. & PNEU.	94400	2	188,800
ELECTRICAL CONTROL	11900	2	23,800
UMBILICAL HOUSING (PLATE)	12,000	2	24,000
DISCONNECT DEVISE	6000	2	12,000
ACCESS ARM No 7A RIGGING ASSEMBLY	30000	1	30 000
ACCESS ARM No 8A RIGGING ASSEMBLY	25000	1	25 000
TOWER HYDROLIC & PNEUMATIC CART & RESERVOIR	32,600	1	32,600
TOWER ELECTRICAL, A.G.C.	257,500	1	257,500
LAUNCH CONTROL CENTER (ELECTRICAL)	31,000	1	31,000
TOTAL ESTIMATED COST ONE SET OF ARMS			1,726,000
TRANSPORT TRAILERS	10,000	[illegible]	110,000
TEST SITE (MSFC)	1,355,000	1	1,355,000

Figure 12-1. Cost Estimates

The estimate includes all hydraulic, pneumatic, electrical, and structural components for operation of the umbilical arms. All conduit and/or lines running up the tower which furnish control to the arms are included. No cost for cabling and/or lines was determined between the umbilical tower and the launch control center.

The cost of rigging, that is, propellant lines, electrical cable, etc., required for umbilical connections included only those lines running from the ground half umbilical plate to the tower.

Test site and test facilities costs have been estimated and are included.

A cost consideration has been made for the vehicle which will transport the umbilical arms. It was assumed that one trailer would be required for each of the arms.

NOTE

Cost estimates were prepared by Brown Engineering Company

SECTION XIII

CONCLUSIONS

Conclusions reached by the C-5 Umbilical Arms Study Group are as follows:

(1) That a vertical-faced tower be used to accommodate location of umbilical arms at various levels.

(2) That an open-truss-framed, horizontally-swinging umbilical arm be used, in order to minimize requirements imposed on design of the VAB and to take full advantage of previous experience with this configuration.

(3) That a rotary actuator be employed to retract the arm; and that this system of actuation be backed up by a gravity-powered system.

(4) That critical valve complexes be located on the tower deck near the base of each arm.

(5) That movable extension platforms be employed to bridge the gap between the ends of the arms and the vehicle access areas.

(6) That NASA ball-and-cone type propellant couplings be used.

(7) That positive handling mechanisms be utilized for disconnecting umbilicals.

(8) That reconnect is not feasible for early C-5 launches; however, a comprehensive design and development program should be initiated to establish firm criteria for a reconnect mechanism for use with later Earth-orbital missions.

(9) That interface locations be assigned at the point where stage peculiarity has disappeared.

(10) That hardware be standardized at the lowest practical level.

(11) That studies be made of the effect of vehicle exhaust on the umbilical components.

(12) Control systems should be designed along the philosophies and guidelines presented in Section VII, paragraphs L and M.

NOTE

A detailed design solution to any of the problems encountered in this study will require rigorous design investigation and continuous coordination with vehicle requirements.

APPROVAL August 15, 1962

CONCEPT STUDY REPORT
LAUNCH COMPLEX 39 UMBILICAL ARMS

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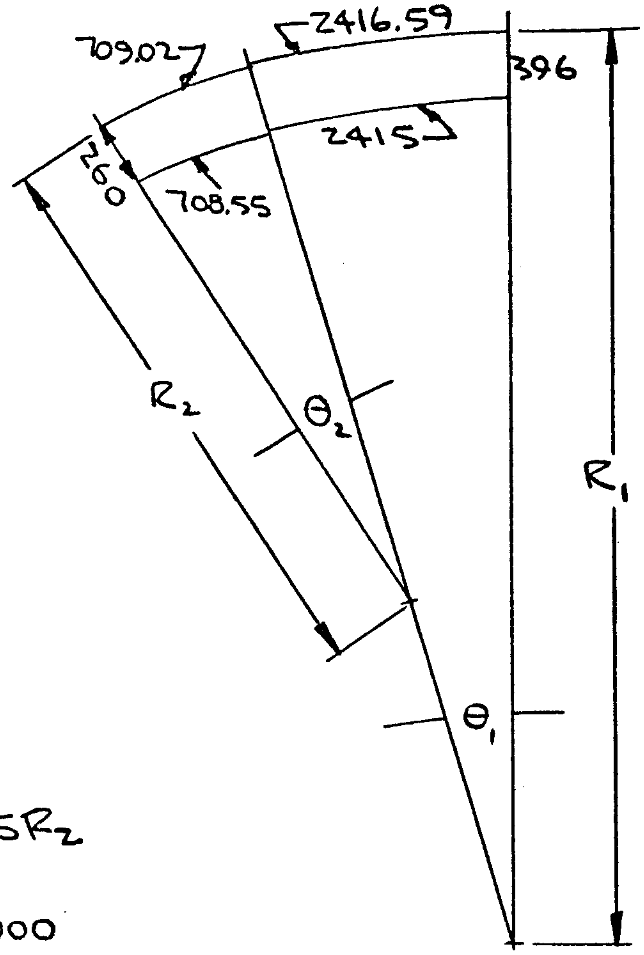
THERMAL BENDING OF C-5 VEHICLE

LATERAL DEFLECTION DUE TO 120°F SKIN TEMPERATURE ON ONE SIDE AND 70°F ON THE OTHER SIDE.



$$\frac{2416.59}{R_1} = \frac{2415}{R_1 - 396}$$

$$2416.59 R_1 - 396(2416.59) = 2415 R_1$$

$$R_1 = \frac{(396)(2416.59)}{1.59} = 602{,}000$$

$$\frac{709.02}{R_2} = \frac{708.55}{R_2 - 260}$$

$$709.02 R_2 - (709.02)(260) = 708.55 R_2$$

$$R_2 = \frac{(709.02)(260)}{.47} = 392{,}000$$

$$\frac{C}{180} = \frac{S}{\theta}$$

$$\frac{2\pi\,(602{,}000)}{180} = \frac{2416.59}{\theta_1} \qquad \therefore\ \theta_1 = \frac{(2416.59)(180)}{(2\pi)(602{,}000)}$$

$$\theta_1 = 0.115°$$

$$\frac{2\pi\,(392{,}000)}{180} = \frac{709.2}{\theta_2} \qquad \therefore\ \theta_2 = \frac{(709.2)(180)}{(2\pi)(392{,}000)}$$

$$\theta_2 = 0.518°$$

CALC	Bozuck	6-13-67	REVISED	DATE	THERMAL BENDING OF C-5 VEHICLE	
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APR					THE BOEING COMPANY	PAGE 1 OF 2

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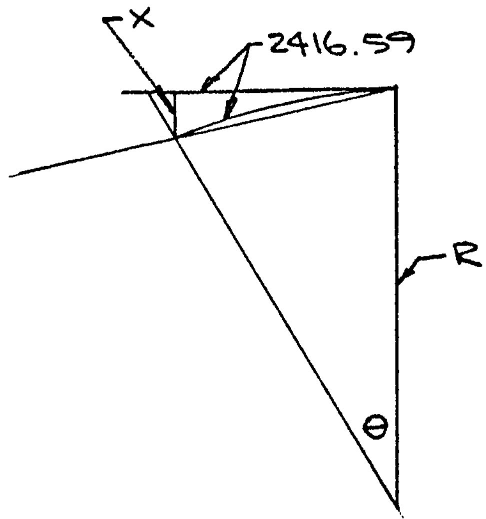
$$\sin\left(\frac{0.115^\circ}{2}\right) = \frac{x}{2416.59}$$

$$x = (2416.59)\sin(0.0575^\circ)$$

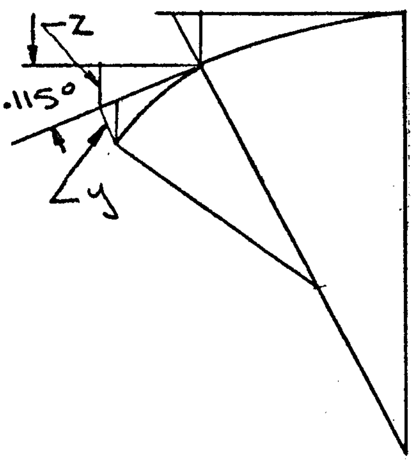
$$x = (2416.59)(0.00100) = 2.42 \text{ IN.}$$

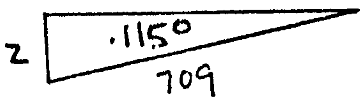


$$\sin\left(\frac{.518^\circ}{2}\right) = \frac{y}{709}$$

$$y = (709)(\sin .259^\circ)$$

$$y = (709)(.00452) = 3.20 \text{ IN}$$





$$\sin .115^\circ = \frac{z}{709}$$

$$z = (709)(.00201) = 1.42$$

TOTAL LATERAL DEFLECTION AT
TOP OF S-IVB STAGE

$$2.42 + 3.20 + 1.42 = 7.04 \text{ IN}$$

TOTAL LATERAL DEFLECTION AT
TOP OF S-II STAGE = 2.42 IN

CALC	Beaver	6-13-6?	REVISED	DATE	THERMAL BENDING OF C-5 VEHICLE	
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A-2 8000

C-5 VEHICLE LENGTH CHANGE

DEFLECTION OF EACH STAGE DUE TO ALL DEAD WEIGHT ABOVE THAT STAGE.

A. DEFLECTION OF S-IVB DUE TO APOLLO LOAD.

$$\delta = \frac{Pl}{AE}$$

E = 10^7 FOR Al FROM MARK'S HANDBOOK 6-68

$$\delta = \frac{(22,990)(708.55)}{(91.4)(10^7)} = -.0178$$

[1]

SEE PP 8 THESE CALCULATIONS

B. DEFLECTION OF S-II DUE TO APOLLO AND S-IVB LOADS.

$$\delta = \frac{Pl}{AE}$$

[3] [2]

$$\delta = \frac{(22,990 + 150,000)(619)}{(213)(10^7)} = -.0502$$

[2]

[2]

$$\delta = \frac{(22,990 + 150,000)(359)}{(249)(10^7)} = -.0250$$

[2]

C. DEFLECTION OF S-IC STAGE DUE TO APOLLO, S-IVB, AND S-II.

a) ABOVE LOX TANK

[5] → {80,000# S-II WT. EMPTY}

$$\delta = \frac{Pl}{AE}$$

CALC	Beaver	6-8-62	REVISED	DATE	C-5 VEHICLE LENGTH CHANGE	
CHECK						
APR						
APR					THE BOEING COMPANY	PAGE 1 OF 10

U3 4038 8000

$$\delta = \frac{(252{,}990)(\overset{[6]}{121})}{(\underset{[9]}{259})(10^7)} = .019$$

b) LOX TANK

$$\delta = \frac{P\ell}{AE}$$

$$\delta = \frac{(252{,}990)(\overset{[6]}{525})}{(\underset{[9]}{329})(10^7)} - .0404$$

c) BETWEEN TANKS

$$\delta = \frac{P\ell}{AE}$$

$$\delta = \frac{(252{,}990)(\overset{[6]}{270})}{(\underset{[9]}{239})(10^7)} = -.0285$$

d) PROPELLENT TANK

$$\delta = \frac{P\ell}{AE}$$

$$\delta = \frac{(252{,}990)(\overset{[6]}{279})}{(\underset{[9]}{329})(10^7)} = -.0214$$

e) BELOW PROPELLENT TANK

$$\delta = \frac{P\ell}{AE}$$

$$\delta = \frac{(252{,}990)(242)}{(715)(10^7)} = -.0086$$

[6]

SEE PP 8 OF THESE CALCULATIONS

ASSEMBLED C-5 VEHICLE IN SUNSHINE THAT PRODUCES A SKIN TEMP OF 120°F.

$$\delta = (3123\text{ in})(120-70)°F\,(13.3\times10^{6}\text{ in/in/°F})$$

$$\delta = \boxed{2.06\text{ INCHES}}$$

EXPANSION OF Al FROM MARK'S HANDBOOK 6-68

FOR ANY SKIN TEMPERATURE:

$$\delta = \frac{(3123\text{ IN})(13.3)}{10^6}(x-70) = (.0415)(x-70) =$$

WHERE X = SKIN TEMP.

DEFLECTIONS DUE TO COLD FLUIDS.

A. LH_2 TANK SHRINKAGE IN S-IVB

AVERAGE VALUE FROM [8]

$$\delta = (311)(423+70)(7.69\times10^{-6}) = -1.18$$

B. LH_2 TANK SHRINKAGE IN S-II

$$\delta = (579)(423+70)(7.69\times10^{-6}) = -2.20$$

c) LOX TANK SHRINKAGE IN S-IC

$$\delta = (525)(300+70)(10.3\times10^{-6}) = -2.00$$

AVERAGE VALUE FROM [8]

CALC	Boyer	6-8-68	REVISED	DATE	C-5 VEHICLE LENGTH CHANGE	
CHECK						
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U3 4038 E 300

DEFLECTION OF EACH STAGE SECTION DUE TO THE FUEL LOAD ABOVE IT.

A. DEFLECTION OF S-IVB DUE TO FUEL LOAD OF APOLLO

$$\delta = \frac{P\ell}{AE}$$

[7]

$$\delta = \frac{(29,960)(708.55)}{(91.4)(10^7)} = -.0232$$

B. DEFLECTION OF S-II STAGE DUE TO THE FUEL TANKS ABOVE.

a) ABOVE LH_2 TANK

$$\delta = \frac{P\ell}{AE}$$

[3]

$$\delta = \frac{(29,960 + 230,000)(619)}{(213)(10^7)} = -.0755$$

b) BELOW LH_2 TANK

$$\delta = \frac{P\ell}{AE}$$

$$\delta = \frac{(\overbrace{29,960 + 230,000 + 941,370}^{1,201,330})(359)}{(249)(10^7)} = -.173$$

C. DEFLECTION OF SI-C DUE TO FUEL LOADS ABOVE.

a) ABOVE LOX TANK

$$\delta = \frac{P\ell}{AE}$$

$$\delta = \frac{(1,201,330)(121)}{(329)(10^7)} = -.056$$

CALC	Bezner	6-8-67	REVISED	DATE	C-5 VEHICLE LENGTH CHANGE	
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b) LOX TANK

$$\delta = \frac{P\ell}{AE}$$

$$\delta = \frac{(1{,}201{,}330)(525)}{(329)(10^7)} = -.192$$

c) BETWEEN TANKS

$$\delta = \frac{P\ell}{AE}$$

[4]

$$\delta = \frac{(\overbrace{1{,}201{,}330 + 3{,}193{,}000}^{4{,}394{,}330})(270)}{(239)(10^7)} = -.496$$

d) RP-1 TANK

$$\delta = \frac{P\ell}{AE}$$

$$\delta = \frac{(4{,}394{,}330)(279)}{(329)(10^7)} = -.372$$

e) BELOW RP-1 TANK

$$\delta = \frac{P\ell}{AE}$$

$$\delta = \frac{(4{,}394{,}330 + 1{,}403{,}000)(279)}{(715)(10^7)} = .226$$

SEE PP 8 OF THESE CALCULATIONS

CALC	Bezuer	6-8-62	REVISED	DATE	C-5 VEHICLE LENGTH CHANGE	
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DEFLECTION DUE TO PRESSURE IN TANK AT FILL.

A. LH_2 TANK OF S-IVB

$$P = \frac{\pi d^2}{4}$$

$$P = \frac{(\pi)(260)^2}{4}\overset{[7]}{(4)} = 212{,}000$$

$$\delta = \frac{P\ell}{AE}$$

$$\delta = \frac{(212{,}000)(311)}{(91.4)(10^7)} = +.0722$$

B. LH_2 TANK OF S-II

$$P = \frac{\pi d^2}{4}$$

$$P = \frac{(\pi)[(33)(12)]^2}{4}(15) = 1{,}849{,}000$$

$$\delta = \frac{P\ell}{AE}$$

$$\delta = \frac{(1{,}849{,}000)(579)}{(213)(10^7)} = +.51$$

C. LOX TANK OF SI-C

$$P = \frac{\pi d^2}{4}$$

$$P = \frac{(\pi)[(33)(12)]^2}{4}(10) = 1{,}231{,}000$$

$$\delta = \frac{P\ell}{A_3 E}$$

$$\delta = \frac{(1{,}231{,}000)(525)}{(329)(10^7)} = +.197$$

CALC	Beaver	6-8-62	REVISED	DATE	C-5 VEHICLE LENGTH CHANGE	
CHECK						
APR						
APR					THE BOEING COMPANY	PAGE 6 OF 10

A-8 18000

DEFLECTION DUE TO PRESSURE IN TANKS AT STANDBY.

A. LH_2 TANKS OF S-IVB

$$P = \frac{\pi d^2}{4}$$

$$P = \frac{(\pi)(260)^2(2)}{4} = 106{,}000$$

$$\delta = \frac{Pl}{AE}$$

$$\delta = \frac{(106{,}000)(311)}{(91.4)(10^7)} = .0361$$

B. LH_2 TANKS OF S-II

(SAME AS FILL)

C. LOX TANKS OF SI-C

$$P = \frac{\pi d^2}{4}$$

$$P = \frac{\pi\left[(33)(12)\right]^2(3)}{4} = 370{,}000$$

$$\delta = \frac{Pl}{AE}$$

$$\delta = \frac{(370{,}000)(525)}{(329)(10^7)} = +.0591$$

CALC	Beaver	6-8-62	REVISED	DATE	C-5 VEHICLE LENGTH CHANGE	
CHECK						
APR						
APR					THE BOEING COMPANY	PAGE 7 OF 10

AREA OF LOWER SKIN SECTION

$$A = ct = \pi dt = \pi(396)(.32) = 398 \qquad 398$$

[9]

STIFFNERS

$$(12.2)(.1)(96) = 117.1 \qquad 117.1$$

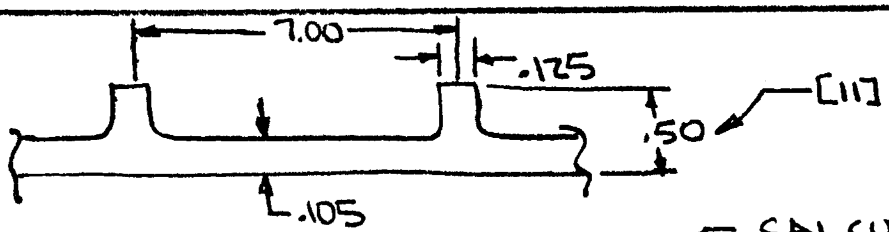
LENGTH
THICKNESS
QUANITY

HOLDDOWN-SUPPORT POSTS

$$(4)(50\ \text{IN}^2) = 200 \qquad \underline{200}$$

[10]

715.1



CALCULATIONS BY
R.P. JOHNSTON 6-15-62

$$\frac{(7)(.105) + (.395)(.125)}{7} = .112\ \text{IN}$$

$$A = \pi Dt = \pi(260)(.112) = 914\ \text{in}^2$$

CALC	Beaver	6-8-62	REVISED	DATE	C-5 VEHICLE LENGTH CHANGE	
CHECK						
APR						
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[8] FIGURE 104, PAGE 107, CRYOGENIC DATA BOOK PB151837

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February 27, 1962

-PRELIMINARY INVESTIGATION FOR S-IV-B-

HANDLING, STORAGE, AND TRANSFER

OF

MONOMETHYL HYDRAZINE AND NITROGEN TETROXIDE

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Dept. A2-263

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1. GENERAL PRINCIPLES

1.1 INTRODUCTION

This preliminary investigation covers the handling and storage of Nitrogen Tetroxide and Monomethyl Hydrazine. Accordingly, information on the general properties of these materials is given so that hazards will be recognized and understood. However, the principal intent of this report is to serve as a guide in establishing the necessary ground rules for the design and fabrication of the GSE for the S-IV-B Attitude Control and Positive Ullage System required at the Sacramento Test Facility and possibly at Cape Canaveral.

1.2 S-IV-B ATTITUDE CONTROL AND POSITIVE ULLAGE SYSTEM

The Attitude Control and Positive Ullage System incorporates eight nozzles arranged into two groups of four. The function of the attitude control portion of the system is to supply approximately 200-300 pounds of thrust to compensate for the pitch, roll and yaw of the S-IV-B vehicle during coasting and docking operations at zero gravity. The positive ullage portion of the system consist of two nozzles; one in each nozzle grouping. Their function is threefold and also occurs at zero gravity. These two nozzles are used to provide positive ullage for the following operations: Firing the J-2 engine, venting main J-2 engine propellant tanks, and accurate propellant measurement within the J-2 engine propellant tanks. The maximum required vehicle propellant loads for the Attitude Control and Positive Ullage System are 499 pounds of Nitrogen Tetroxide and 216 pounds of Monomethyl Hydrazine. Each propellant tank is equipped with a flexible bladder, which is pressurized to 200-250 PSIG from a common 2500-3000 pound ambient helium supply bottle, to permit the positive expulsion of propellants. Due to the freezing temperature of the propellants, the propellant tanks will be fabricated of aluminum (2014) and probably insulated. It has also been suggested that additives might be mixed with propellants to lower their freezing temperatures provided that the performance losses are not too great. Both propellant tanks and the 2500-3000 pound helium pressure supply bottle will be located either outside the vehicle or within the boat-tail section.

1.3 GENERAL PROPERTIES OF NITROGEN TETROXIDE (N_2O_4)

Type	Hypergolic Oxidizer
Chemical Composition	Nitrogen Tetroxide (N_2O_4) Nitrogen Dioxide (NO_2) -Equilibrium Mixture-
Chemical Nature	Corrosive Oxidizing Agent
Other Trade Names	Dinitrogen Tetroxide Nitrogen Peroxide Liquid Nitrogen Dioxide
Propellant Procuring Specification	MIL-P-26539 (USAF)
Moisture Content	Not more than 1% water.
Color	Brown liquid; yellowish to reddish brown vapor.
Toxicity	Extremely toxic (2.5 PPM/Day max. allowable).
Odor	Characteristicly pungent.
Sensitivity	Not to mechanical shock, heat or detonation.
Fire Hazard	Non flammable with air; however, it can support combustion with combustible materials.
Boiling Point, $^{\circ}F$	70.1
Freezing Point, $^{\circ}F$	11.84

1.3 (Continued)

Density at 68°F, LB/GAL.	12.08
Specific Gravity of Gas at 70°F, 1 ATM	2.83
Specific Heat at 0°F, BTU/LB	0.36
Molecular Weight	92
Critical Temperature, °F	316.8
Critical Pressure, PSIG	1455
Critical Density, LB/GAL.	4.67
Viscosity, Centipoise	
At 70°F, 1 ATM	0.41
At 160°F, 1 ATM	0.22
At 250°F, 1 ATM	0.09
Thermal Conductivity, BTU/HR Ft. F.	
At 40°F	0.081
At 100°F	0.072
At 160°F	0.056
Heat of Formation (Liquid) at 25°C, CAL/MOLE	-6800
Heat of Vaporization at Boiling Point, CAL/MOLE	9110
Heat of Fusion at Freezing Point, CAL/MOLE	3502

1.3 (Continued)

Vapor Pressure, PSIG	
At 32°F	-9.6
At 70°F	-0.1
At 90°F	10
At 100°F	16
At 120°F	34
At 140°F	59
At 160°F	97
Solubility	Soluble in water forming Nitric and Nitrous Acids.
Stability	Very stable at room temperature. It begins at dissociate at 302°F into Nitric Oxide and Free Oxygen; however, upon cooling, it reforms into Nitrogen Tetroxide.
Storage and Shipping	May be stored and shipped in low pressure carbon steel containers since vapor pressure at 140°F is only 59 PSIG, and the corrosivity, at 1% water content or less, is negligible for an indefinite period.
Approximate Cost, $/LB	0.075

1.4 GENERAL PROPERTIES OF MONOMETHYL HYDRAZINE (MMH)-($CH_3N_2H_3$)

Type	Hypergolic-Hygroscopic Fuel
Chemical Composition	CH_3NHNH_2 or $CH_3N_2H_3$
Chemical Nature	Susceptible to Catalytic Decomposition
Other Trade Names	None
Propellant Procurement Specification	Commercial
Moisture Content (Mfg. Standard)	2% Water and Amines
Color	Clear and Colorless
Toxicity	Respiratory irritant and convulsant, (more sever than Hydrazine) 0.1 to 0.5 PPM/Day maximum.
Odor	Similar to lower Aliphatic Amines.
Sensitivity	Sensitive to Catalytic oxidation, but not sensitive to impact or friction.
Fire Hazard	Vapors are dangerous: Capable of spontaneous ignition when exposed to air on large surfaces (such as rags).
Boiling Point, $^{\circ}F$	189.5
Freezing Point, $^{\circ}F$	-62.3
Density at $77^{\circ}F$, LB/FT^3	54.6

1.4 (Continued)

Specific Gravity at 77°F, 1 ATM	0.874
Specific Heat	Not available
Molecular Weight	46.075
Critical Temperature, °F	609
Critical Pressure, PSIA	1195
Critical Density, LB/GAL	Not available
Viscosity at 77°F, Centipoise	.078
Thermal Conductivity	Not available
Heat of Formation (Liquid) at 25°C, CAL/MOLE	+12700
Heat of Vaporization at 25°C CAL/MOLE	9648
Heat of Fusion at Freezing Point, CAL/MOLE	2491
Vapor Pressure, PSIA	
At 77°F	0.960
At 158°F	7.73
Solubility	MMH is miscible with water.
Stability	Stable over entended temperature range.
Storage and Shipping	It can be stored & shipped safely without deterioration if air supply is limited.

1.4 (Continued)

Approximate Cost, $/LB	3.00

Comparisions of Monomethyl Hydrazine: Monomethyl Hydrazine (MMH) is a very reactive chemical which will undergo most of the reactions of Unsymmetrical Dimethylhydrazine (UDMH) but yielding Monomethyl rather than Dimethyl reaction products. The thermodynamic properties of MMH are very close to those of a 50-50 mixture of Anhydrous Hydrazine and UDMH, but its lower freezing point makes it of interest as a replacement for this mixture. The density impulse of MMH is superior to that of either UDMH or 50-50 mixtures of Anhydrous Hydrazine and UDMH. In addition, it is usually preferable to have a one-component fuel rather than a two-component fuel, other properties being nearly equal.

1.5 PERSONNEL TRAINING

All operating personnel should be taught the nature of Nitrogen Tetroxide and Monomethyl Hydrazine, and the general principles of safe conduct in handling, storage, and use of such materials. The materials described here can be handled safely when certain simple basic principles are known and followed faithfully.

> IGNORANCE OR CARELESSNESS CAN RESULT IN PERMANENT INJURY OR DEATH. EACH PERSON ENGAGED IN THIS WORK SHOULD BE TAUGHT PROCEDURES OF SELF-AID AND FIRST AID.

1.6 LIGHTNING PROTECTION SYSTEMS

The details of construction and installation of lightning protection systems shall conform with the regulations of the National Bureau of Standards Handbook H-40, "Code for Protection Against Lightning", NBFU pam. No. 70 or NFPA No. 70. Materials used shall be approved by the Underwriters Labs, and be so labled.

1.7 STATIC ELECTRICITY

All conductive parts of equipment should be grounded by providing electrically continuous paths to ground to allow the static charges to dissipate as fast as they are generated. The flow of fluids in pipes and excessive turbulence of storage tank liquid surfaces lead to static charge generation; therefore, liquid turbulence in filling operations must be held to a minimum. The problem of static electricity should be taken into careful consideration especially with the storage and transfer of Monomethyl Hydrazine whose vapors create a very dangerous fire hazard.

2 HAZARDS

The three hazards to be dealt with in operations involving Nitrogen Tetroxide and Monomethyl Hydrazine are fire, explosion, and toxicity (poisoning or chemical burns).

2.1 FIRE

Nitrogen Tetroxide: Liquid and Gaseous Nitrogen Tetroxide are stable at ordinary temperatures. Liquid Nitrogen Tetroxide, by itself, will not burn but will support combustion and is highly toxic. The oxygen content of Nitrogen Tetroxide is about 70% by weight. When mixed with a fuel it readily supports combustion. In case of spillage, all surfaces of equipment contacted with Liquid Nitrogen Tetroxide should be flushed throughly with large quantities of water which will accelerate the fuming of the liquid. In case of fire, shut off all propellant flow and dilute the Nitrogen Tetroxide by applying large quantities of water.

Monomethyl Hydrazine: The fire hazards of Monomethyl Hydrazine are close to those of Hydrazine and UDMH. Therefore, the oxidation of MMH by oxygen in the air and the fammability of MMH vapors in the air make

2.1 (Continued)

it necessary to use an inert atmosphere over MMH at all times. The possibility of sparking in an area where MMH vapors may be present must be strictly avoided. Buildings in which MMH is stored or handled should be well ventilated to prevent accumlation of MMH vapors. Electrical equipment of all types should be vapor tight and explosion-proof. All metallic apparatus, including storage tanks, must be grounded to prevent the possibility of static sparking. Spark-proof tools should be used for working on any MMH system. Also the catalytic decomposition of MMH by iron rust will cause spontaneous fire. MMH should not be allowed to contact rust or other decomposition catalysts. Water should be used in large quantities to dilute and wash away spilled MMH and to combat MMH fires.

2.2 EXPLOSION

Nitrogen Tetroxide: Nitrogen Tetroxide is an oxidizer; therefore, non-hypergolic mixtures with rocket fuels present an explosion hazard when mixed with it. Nitrogen Tetroxide should be stored and handled in well ventilated spaces, remote from fuels. Storage areas should be maintained at moderate temperatures.

Monomethyl Hydrazine: Monomethyl Hydrazine should be stored away from oxidizers and catalytic agents and from possible sources of ignition such as electric spark or flame. All equipment must be grounded to avoid any static charge, and all electrical equipment shall be of the class and group recommended in the National Electrical Codes. Monomethyl Hydrazine must be stored and handled under an inert atmosphere at all times. All confined spaces shall be well ventilated to minimize build up of an explosive mixture.

2.3 HEALTH

Nitrogen Tetroxide: Nitrogen Tetroxide in liquid form is corrosive to body tissues, and severe burns of skin and eyes can result from more than momentary contact. If liquid is splashed on body or into eyes,

2.3 (Continued)

wash same with large quantities of water. Inhalation of the toxic vapors is normally the most serious hazard in handling Nitrogen Tetroxide. The threshold limit value of the fumes is 5 PPM (9mg/ cu m) expressed as Nitrogen Dioxide, or 2.5 PPM (9mg/ cu m) expressed as Nitrogen Tetroxide. The color of the fumes is not a reliable index of degree of toxic hazard. A man may, without serious discomfort at the time, breathe an atmosphere containing a dangerous concentration of Nitrogen Tetroxide, and then hours later become severly ill. Persons exposed to the fumes should be carried and not allowed to walk. Absolute rest is essential. A physican should be notified at once.

Monomethyl Hydrazine: Monomethyl Hydrazine if spilled onto the skin or into the eyes can cause severe local damage or burns. In addition, it can penerate skin to cause systemic effects similar to those produced when swallowed or inhaled. If Monomethyl Hydrazine is spilled onto the body or into the eyes, flush with large quantities of water. Monomethyl Hydrazine vapors are toxic and should not be premitted to come in contact with the eyes. If inhaled, the vapor causes systemic and local (eye and respiratory tract irritation) effects. A physican should be notified at once.

3. SAFETY REQUIREMENTS

3.1 Propellant Handling-Personnel Protection

Nitrogen Tetroxide: Gloves and boots which do not let Nitrogen Tetroxide through to the skin must be worn by personnel handling Nitrogen Tetroxide. The vinyl coated glove, type R-1, under specification MIL-G-4244 allows free movement of the fingers and meets the above requirements. Boots made of natural or reclaimed rubber or GR-S may be used with reasonable safety if contamination is washed off quickly. Boots of the approved materials, per MIL-Specification, are not commerically available.

3.1 (Continued)

Clothing must cover all body parts subject to exposure. Body protective clothing, Specification MIL-S4553 (USAF) Suit, Protective, Acid and Fuel Resistant, Vinyl Fiberglass, Inner Type MA-1 and MIL-S-12527 (QMC) Suit Protective, Acid and Fuel Resistant, are suitable. Polyethylene or fiberglass clothing impregnated with acid resisting plastics, such as teflon and kel-f, are excellant for handling Nitrogen Tetroxide. An approved type of hood must be worn for head protection. Whenever the concentration of Nitrogen Tetroxide fumes exceed 2.5 PPM approved respiratory protection should be worn. An approved self-contained breathing apparatus will provide the most reliable respiratory portection. The canister type mask is of limited value.

Monomethyl Hydrazine: Personnel handling Monomethyl Hydrazine should wear rubber gloves and boots identical to the specifications outlined for handling Nitrogen Tetroxide.

Under normal use conditions, a plastic face shield, or preferably, vapor-tight goggles should be worn. Wrist and arm protectors, and a rubber type apron should also be worn while handling Monomethyl Hydrazine. Whenever there is possibility of gross splashing, portective clothing identical to the specifications outlined for handling Nitrogen Tetroxide should be worn.

Whenever Monomethyl Hydrazine is being handled, approved respiratory protection should be worn. The odor should not be depended upon to indicate the need for wearing respiratory protective devices because the odor threshold value is above the maximum allowable concentration. Approved self-contained breathing apparatus or a full face ammonia mask should be worn. The ammonia mask should not be utilized whenever there are potential or actual exposures to moderate or high concentrations of vapors. Although the ammonia mask is used in the commercial handling of MMH, it has not been firmly established as to what degree of protection is afforded.

3.2 PROPELLANT STORAGE

Fire and explosion hazards have an important influence on the design of main propellant storage units and on their location with respect to each other and to populated buildings and areas. Fuels and oxidizers must be separated by distance (approximately 50 feet) or by barriers. Ample water for fire fighting and decontamination must be provided. It is recommended that both Nitrogen Tetroxide and MMH be stored in bulk tanks not exceding a one ton capacity. The bulk storage system for each chemical should be installed on a covered concrete base, or suitable substitute, with an adequate drainage and decontaminating system. Diking, cleaning and preservation, and electrical requirements should be observed. All packing gland seals around pump shafts, valves, etc. should be protected by polyethylene shields to prevent propellants from spraying on operators in case of failure.

4. SIMILAR EXISTING PROPELLANT SYSTEMS

Presently, no propellant system utilizes MMH; however, it is being proposed for the Apollo program. Missiles powered, or to be powered, by various other types of Hydrazine fules are Nike, Bom arc, Titan, Dyan-Soar, Vanguard, Pioneer, Sparrow, Bullpup, and many others. Nitrogen Tetroxide is consistently being used as an oxidizer. The Titan II Booster and Titan II sustainer have Aerojet engines, XLR87-AJ-3, whose propellant is Nitrogen Tetroxide and a 50-50 mixture of UDMH and Hydrazine. Also Rocketdyne's P-7 Engine, the Aspen, proposes to use a mixture of Nitrogen Tetroxide and UDMH (Unsymmetrical Dimethylhydrazine).

5. MATERIALS

Nitrogen Tetroxide: Although Nitrogen Tetroxide at ordinary temperatures and pressures is not corrosive to most common metals, selection of metals for this service should be governed by the moisture content of the Nitrogen Tetroxide. For service when moisture is 0.1% or less use carbon steels, aluminum, stainless steels, nickel, and inconel. When

5. (Continued)

moisture content is greater than 0.1% use 300 series stainless steel. Acceptable non metals are ceramic, pyrex glass, teflon, kel-f, asbestos (cotton free), and polyethylene (limited use). Acceptable lubricants are fluorolube series, nordcoseal-147 and DC 234S, water glass and graphite. Since Hydrocarbon lubricants react with oxidizers, they must be avoided.

Monomethyl Hydrazine: The capatibility of MMH with metals is nearly the same as that of Hydrazine, except that MMH attacks organic materials more readily. Recommended materials for storage and handling include type 303, 304, 316, 321, 347, and 4130 stainless steels and type 3S, 52S, 996 and 6061-50 aluminums. Metals containing copper, lead, zinc or over 0.5% molybdenum should be strictly avoided. Satisfactory non-metals are teflon, silicone rubber, and high density polyethylene. Flexible hoses should be teflon and should be enclosed within stainless steel brading. To date, a completely satisfactory lubricant has not been developed. "Q"-seal, Quingley Company, is being used with fair results.

6. LINE AND HARDWARE CONNECTIONS

Nitrogen Tetroxide is a very toxic-hypergolic-hygrosopic oxidizer and Monomethyl Hydrazine is a very toxic hypergolic fuel whose vapors create a definite fire hazard; therefore, installation of piping, fittings, and hardware should be accomplished by welding. Both propellants should be transferred within a close loop system.

7. ELECTRICAL EQUIPMENT

Nitrogen Tetroxide: All electrical lines and wires shall be installed in rigid metal conduits, while all electrical controls, junction boxes, and panels shall be vapor and weather proof. A master switch to shut off all power in the Nitrogen Tetroxide handling and storage area shall be provided for emergency use. This switch shall be located in an accessible spot outside the Nitrogen Tetroxide area.

7. (Continued)

Monomethyl Hydrazine: The electrical installation in transfer and storage areas shall conform to the National Electric Code requirements for Class I, Group D, Division I.

8. DIKING

Both the Nitrogen Tetroxide and MMH storage tanks should be surrounded by a dike of sufficient height to hold 10% over maximum storage capacity.

9. CLEANING AND PRESERVATION

Nitrogen Tetroxide Equipment: Remove rust and scale mechanically or with a nitric-hydrofluric acid mixture- only for stainless steel equipment. For both aluminum and stainless steel equipment, proceed as follows: Degrease with solvent (use special precaution to avoid exposure to fumes). Rinse thoroughly with alcohol and then rinse with water or steam clean. Bathe equipment in a 4% detergent solution and heat to 150°F (max.), or 120°F if plastic parts are present, for 30 minutes. Acid pickle all stainless steel parts using a 40-50% nitric acid solution. Rinse with distilled water and blow dry with nitrogen gas. Package small parts in polyethylene bags and close securely until part is ready for use. For large pieces of hardware (valves, tanks, etc.) cover openings with a polyethylene seal and tape until ready for use. Presently, there is not a Douglas Process Standard covering Nitrogen Tetroxide. Douglas Process Engineering has suggested using DPS 4.923, "Fuming Nitric Acid Systems", as a preliminary guide if further information is required.

Monomethyl Hydrazine Equipment: The cleaning and preservation requirements for MMH are identical to Nitrogen Tetroxide except that one additional procedure is required. All equipment is to be subjected to a 20% solution of ammonia hydroxide for a one hour period prior to the distilled water rinse. Equipment should then be dried and sealed per the identical procedures required for MMH. Presently, there is not a Douglas Process Standard covering Monomethyl Hydrazine (MMH). Douglas Process Engineering has suggested using DPS4.922, "Hydrazine and UDMH Systems", as a preliminary guide if further information is required.

10. PROPELLANT STORAGE

10.1 Tank Capacities

Minimum propellant storage capacities should be such as to allow a maximum vehicle propellant loading of 499 pounds of Nitrogen Tetroxide and 216 pounds of MMH. Storage tank's design capacities should include a capacity safety factor in addition to a 10% ullage volume required for blanket pressure and for a possible pressurization transfer system.

10.2 Insulation

Monomethyl Hydrazine can be safely stored without decomposition for a long time and over a wide temperature range. However, Nitrogen Tetroxide due to its high freezing temperature would require its ground storage facilities to be aluminum insulated to counteract environmental temperatures. If additives are required in the Nitrogen Tetroxide vehicle propellant for freezing prevention during vehicle flight in outer space, it would eliminate the need for ground storage insulation.

10.3 Vent System

Due to the gas padding requirements during propellant fill operations for both the vehicle and the GSE propellant storage tanks, it is not feasible to conceive ventless GSE propellant storage tanks. However, if the vehicle propellant tanks' gas padding is displaced by the vehicle propellant tanks' expulsion bladders (which requires a vehicle design change) and a chemical co. shipping drum utilized as a storage tank per paragraph 12.2, a ventless GSE propellant storage tank and transfer system could be conceived.

It is recommended that atmospheric event stacks or breathing equipment be employed for propellant storage tank venting. Either of these venting systems would facilitate the design of a closed loop propellant transfer system. Essentially, this consists of venting each vehicle propellant tank back to its respective GSE propellant storage tank during transfer operations. It is evident that this method is only feasible with a pump or gravity feed propellant transfer system. If a propellant pressurization system is conceived, an additional tank will be required for vehicle vent gas collection. In addition,

10.3 (Continued)

eakh GSE propellant storage tank, if built per the ASME code, would require two pressure relief devices, usually a relief valve and a burst disc. Due to the general properties of the subject propellants, vent lines of adequate size should be provided on the outlets of the pressure relief equipment of each propellant system and discharged into seperate fume scrubbing systems (breathing equipment) or atmospheric vent stacks. When venting each propellant tank to atmosphere, it should be done through seperate stainless steel, type 304, vent stacks located away from the working area and discharging at least 50 feet above the highest operating level.

Padding and Breathing Equipment: MMH requires an inert atmosphere of gaseous nitrogen or helium during propellant storage tank fill, propellant storage, and vehicle propellant fill operations. Nitrogen Tetroxide requires a moisture free atmosphere of helium during the identical type of operations. The gaseous nitrogen and/or helium blanket pressures necessitates the need for GSE propellant storage and vehicle tank breathing equipment, if atmospheric storage tank vent systems are not employed. Breathing equipment can consist of a simple gas wash bottle trap and water seal pot arrangement.

10.4 Locations

Possible Locations for Sacramento Test Facility:

a) Located on the ground and away from the test stand.
b) Located on the test stand itself; each individual propellant storage system (or possibily only the storage tank) would be positioned on the test stand only for propellant transfer and then removed.
c) At a common location suitable for providing propellant transfer to a component test site in addition to the vehicle.

10.4 (Continued)

Possible Locations for Cape Canaveral:

a) In the DAC portion of the boathouse.

b) On the umbilical tower or,

c) on the barge itself provided that the relative distance requirements for different propellant storage systems could be solved.

Final locations will be determined on the basis of propellant storage system design and size with due respect for safety, fire, and explosion hazards.

10.5 Unloading Tank Cars and/or Drums

The propellant storage areas will require GSE for unloading delivery tank cars or drums. Both MMH and Nitrogen Tetroxide may be unloaded either with a pump or by pressure. A tank car or drum blanket pressure of gaseous nitrogen or helium, as required per individual propellant characteristics, will be required for either type of unloading method. Purging and breathing equipment will also be necessary to avoid potential hazards.

11. PURGE SYSTEM

11.1 Vehicle Propellant Tanks

The Nitrogen Tetroxide and MMH vehicle propellant tanks should be subjected to a helium and gaseous nitrogen (or helium) purge respectively, equivalent to a predetermined number of propellant tank volume changes. Each propellant tank should maintain its respective gas padding atmosphere during propellant transfer operations. This condition requires either breathing equipment, atmospheric vent systems, or displacement of the gas padding atmospheres by inflation of the vehicle propellant expulsion bladders which is impossible due to present vehicle design criteria.

11.2 Transfer Lines

Both the Nitrogen Tetroxide and MMH transfer lines should be purged with helium and gaseous nitrogen respectively, prior to and after propellant transfer. All removable lines and line connections which would be used and then stored should be flushed with water and purged dry with gaseous nitrogen.

12. PROPELLANT TRANSFER AND VENTING METHODS

12.1 Gravity Feed

A propellant gravity feed system can be designed either by permanently locating the propellant storage tank at a specific elevation or by raising the storage tank to an elevation prior to propellant transfer. The system could be designed to be completely dependent or independent of facility supplies (blanket and gas purge pressures,power, etc.) at the time of propellant transfer. Figures I and II depict a gravity feed system, permanently located, with a self sustained blanket pressure and breathing system. Comments on alternate design are included in the corresponding equipment nomenclature for figures I and II.

GRAVITY FEED SYSTEM

ITEM NO.	EQUIPMENT NOMENCLATURE AND ALTERNATE DESIGN COMMENTS
1.	Approximate Height: 10 feet; however, with the propellant storage tank in a horizontal position and the blanket pressure supply bottle (Item No.7) relocated, the height could be decreased to approximately 7 feet.
2.	Approximate Width: 5 feet
3.	Approximate Length: 6 feet

ITEM NO. EQUIPMENT NOMENCLATURE AND ALTERNATE DESIGN COMMENTS

4. Propellant Storage Tank: The propellant storage tank could be designed to the exact specific volume required for 100% vehicle fill capacity, or as shown, have a propellant return line with a liquid propellant sense apparatus to indicate 100% vehicle fill capacity.

5. Propellant Storage Tank Saddle Support: Shown as such for illustration.

6. Propellant Storage Tank Platform: Located at an elevation comparable to the vehicle propellant tank location and propellant transfer requirements.

7. Blanket Pressure Supply Bottle: Either gaseous nitrogen or helium for an inert or moisture free atmosphere as applicable.

8. Vehicle Propellant Return Tank: This tank is designed to a specific volume to facilitate a predetermined vehicle propellant discharge required for vehicle propellant expansion during flight. The vehicle propellant discharge tank has to have a blanket pressure applied during propellant entry. Breathing equipment or a suitable substitute will be required to allow for blanket pressure displacement.

9. Liquid Propellant Indicator: Required for 100% vehicle propellant fill criteria. Apparatus may be either a differential pressure transducer, sight glass, or similar equipment.

10. Gas Wash and Trap Bottle: Filled with water and pressurized with a blanket pressure identical to that of the propellant storage tank. This will only allow the differential pressure to escape. This type system is ideal for MMH propellant storage but would require a unique design addition to accommodate a Nitrogen Tetroxide (hygroscopic) propellant storage tank. Possibily a check valve and filter arrangement for both propellant storage tank breathing line (Item No. 18) and the vehicle propellant discharge tank breathing line (Item No. 19) would be adequate to prevent moisture contamination upon removal or loss of blanket pressure.

ITEM NO.	EQUIPMENT NOMENCLATURE AND ALTERNATE DESIGN COMMENTS

11. Seal Pot: Filled with water to the vent line (Item No. 21). Accomplishes final washing of toxic vapors.

12. Skid: The skid is the supporting structure for the propellant storage and transfer system. It may also be conceivable to enclose the skid and create a diking arrangement to catch propellant spillage. This would make the propellant storage and transfer system movable and independent of its location. However, if each propellant storage system is conceived to be positioned in the test stand and removed after propellant transfer, it may be more advantegous to have a single dike located in the test stand to facilitate both propellant systems. Nevertheless, this does not alleviate the need for individual diking for each propellant storage area at its ground location.

13. Bottle Supports: Shown as such for illustration purposes only. It may be feasible to countersink the bottles in order to obtain additional support as well as decreasing the over-all height of the complex.

14. Water Supply and Drain Line: Used to fill and drain the gas wash and trap bottle (Item No. 10) and to fill the seal pot (Item No. 11).

15. Blanket Pressure Supply Line for Gas Wash and Trap Bottle

16. Blanket Pressure Supply Line for Propellant Storage Tank.

17. Blanket Pressure Supply Line for Vehicle Propellant Return Tank

NOTE: Blanket pressures should be the equivalent of 25 to 30 inches of water.

18. Propellant Storage Tank Breathing Line: Vents differential pressure caused by propellant vapors or displacement of blanket pressure during fill operations.

ITEM NO. | EQUIPMENT NOMENCLATURE AND ALTERNATE DESIGN COMMENTS

19. Vehicle Propellant Return Tank Breathing Line: Vents return tank blanket pressure during propellant fill operation.

20. Gas Wash and Trap Bottle Vent Line: Vents differential pressures.

21. Seal Pot Vent Line: Vents water washed vapors to atmosphere.

22. Vehicle Propellant Tank and Propellant Transfer Line Purge Connection: If desired, additional gas pressure bottles could possibly accommodate vehicle propellant tank and transfer line purge requirements.

23. Vehicle Propellant Transfer Line: Provides propellant flow to the vehicle propellant tank.

The vehicle propellant fill quick disconnect connection serves as a nonleak shut-off valve on both ends when separated. Due to the fact that there is no vehicle propellant shut-off valve, a GSE option exixt: Provide a propellant shut-off valve to facilitate purging the propellant fill line prior to "vehicle disconnect", or utilize the quick disconnect connection and perform the purging procedure after "vehicle disconnect". In addition, a purge drain valve connection will be required on the vehicle propellant transfer line.

24. Vehicle Propellant Return Line: Permits vehicle propellant tank blanket pressure displacement, vehts propellant vapors, and recirculates propellant to indicate 100% vehicle fill.

25. Vehicle Propellant Discharge Line: For the displacement of a specific volume of vehicle propellant to permit propellant thermal expansion during vehicle flight.

ITEM NO.	EQUIPMENT NOMENCLATURE AND ALTERNATE DESIGN COMMENTS
26.	Seal Pot Drain Line: To drain water from seal pot.

12.2 Pressurization System

A pressurization propellant transfer system would require an additional tank to create a re-circulating closed loop system. The displacement of blanket pressure and toxic vapors could be accomplished with either a common atmospheric vent stack or with water type breathing equipment identical to that shown in the gravity feed system. A typical pressurization system would be as shown in Figure III.

Since the propellant storage capacities are reasonably low, it may be feasible to utilize the chemical company's shipping drums in lieu of regular propellant storage tanks. The required MMH storage capacity is such that a single 55 gallon drum, presently being used by chemical companies, would be more than sufficient for vehical propellant loading. The Nitrogen Tetroxide storage capacity is such that two 55 gallon drums in parallel would be required. This type of storage would obliterate the need for a common vent stack (or breathing equipment) and blanket pressure for the propellant storage tank. A disadvantage of this type of propellant transfer system is the problem of what to do with any excessive propellant remaining in the storage drums after vehicle propellant transfer. Only three possible solutions exist: Return excess propellant to the chemical co., provide recovery equipment, or consider excess propellant as waste. Also unless arrangements are made with the chemical company as to present drum design, a gasket will be required to effect an airtight seal with the eductor pipe. The main advantage of utilizing the chemical drums is that the drums, as delivered, can be easily fastened to a skid and used directly for vehicle propellant transfer operations. A typical propellant drum storage and transfer system is as shown in Figure IV.

12.3 Transfer Pumps

A propellant transfer pump system could easily be designed to effect a closed loop propellant transfer system relatively independent of its skid location and/or elevation requirements. Canned motor pumps, which eliminate all dynamic seals, are presently available for use with MMH and Nitrogen Tetroxide. A typical transfer pump system is as shown in Figure V. Alternate equipment design comments, as applicable, are stated in the equipment nomenclature section of the gravity feed system.

13. VEHICLE PROPELLANT LOADING REQUIREMENTS

13.1 Line Sizes

The Nitrogen Tetroxide and MMH propellant GSE transfer lines will mate with 1/2 inch stainless steel vehicle quick disconnect connections. To facilitate purging requirements, each propellant tank has a 1/2 inch stainless steel vent line with a solenoid shut-off valve and a vehicle quick disconnect connection. The common 2500-3000 pound helium supply bottle has a 1/4 inch stainless steel fill line teeing directly into the propellant tanks' propellant expulsion bladder pressurization line. The helium fill line is equipped with a 1/4 inch quick disconnect connection.

13.2 Propellant Transfer

The maximum vehicle propellant loads are 499 pounds of Nitrogen Tetroxide and 216 pounds of MMH. Propellant transfer rates have not yet been established but are expected to be very low (approximately 10 GPM) due to the time sequence of propellant loading.

13.3 Time Sequence for Propellant Loading

Nitrogen Tetroxide and MMH may be loaded on the vehicle at any time prior to pressurizing the 2500-3000 pound helium pressure supply bottle. Once the helium supply bottle is pressurized, helium pressure is immediately regulated and supplied to each propellant tank propellant expulsion

13.3 (Continued)

bladder. If the propellant tanks' propellant expulsion bladders are pressurized first, their expansion would prohibit propellant loading.

13.4 Sequence of Operations

a) Prior to propellant transfer operations, purge both vehicle propellant tanks. Maintain an inert atmosphere of gaseous nitrogen or helium within the MMH vehicle propellant tank while loading MMH. Maintain a dry atmosphere of helium within the Nitrogen Tetroxide vehicle propellant tank while loading Nitrogen Tetroxide.

b) Load both vehicle propellant tanks to 100% capacity without creating gas pockets on the upstream side of the vehicle propellant feed valves.

c) Pressurize the 2500-3000 pound helium pressure supply bottle and bleed off a specific volume (to be determined) of each propellant. This will allow helium pressure to slightly expand each propellant tank propellant expulsion bladder and thus provide the necessary cushioning effect to compensate for the propellant thermal expansion in flight.

14. REFERENCES

Coordination was established with the S-IV-B Advance Design Section, Process Engineering, and Safety Engineering. Also the following publications were used as applicable for reference material:

The Handling and Storage of Liquid Propellants, March 1961
Office of the Director of Defense Research and Engineering
Washington 25, D. C.

14. (Continued)

Performance and Properties of Liquid Propellants, Revision "A"
Aerojet-General Corporation, Liquid Rocket Plant
Sacramento, California

Storage and Handling of Dimazine (UDMH- Unsymmetrical Dimethylhydrazine)
Westraco Chlor-Alkali Division
Food Machinery and Chemical Corporation

Nitrogen Tetroxide, Tank Car Unloading and Storage, Drawing No. 28815-1 and 28821-1

Nitrogen Division, Allied Chemical and Dye Corporation
Los Angeles, California

Nitrogen Tetroxide Product Bulletin
Allied Chemical Corporation
Los Angeles, California

Mathieson Monomethyl Hydrazine (MMH)
Olin Mathieson Chemical Corporation
Baltimore 3, Maryland

Dangerous Properties of Industrial Materials
N. Irving Sax

Astronautics, December 1959 and July 1960

GRAVITY FEED SYSTEM

FIGURE I — SKETCH

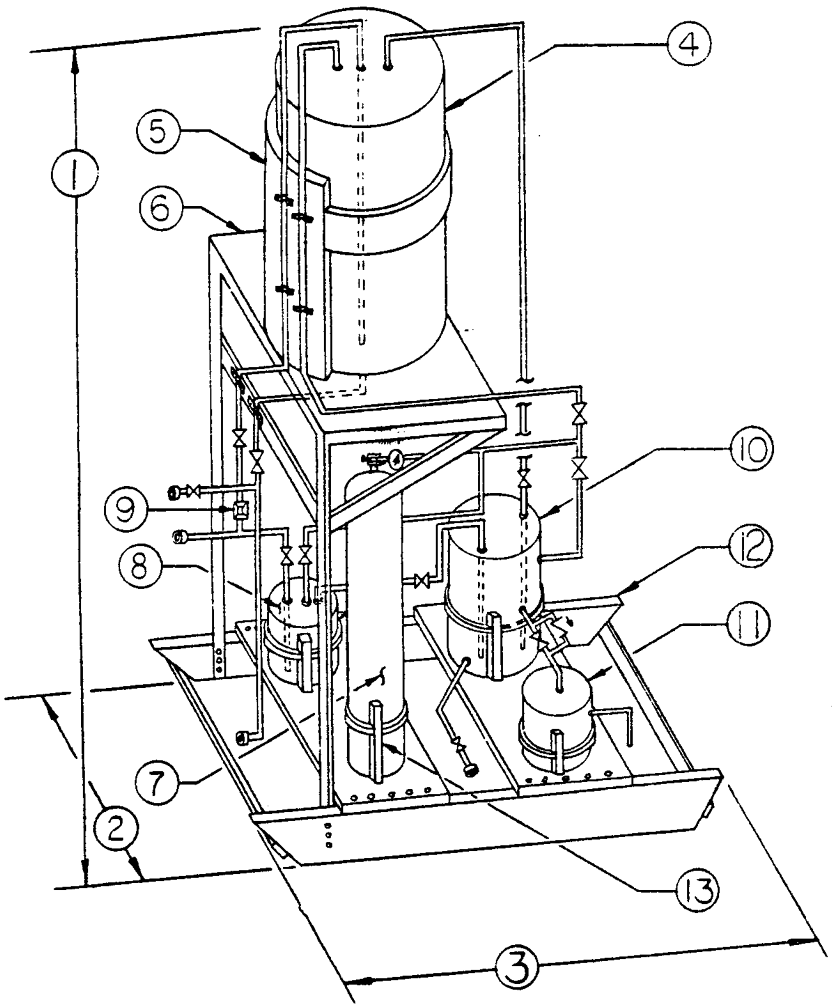

FIGURE II — FLOW DIAGRAM

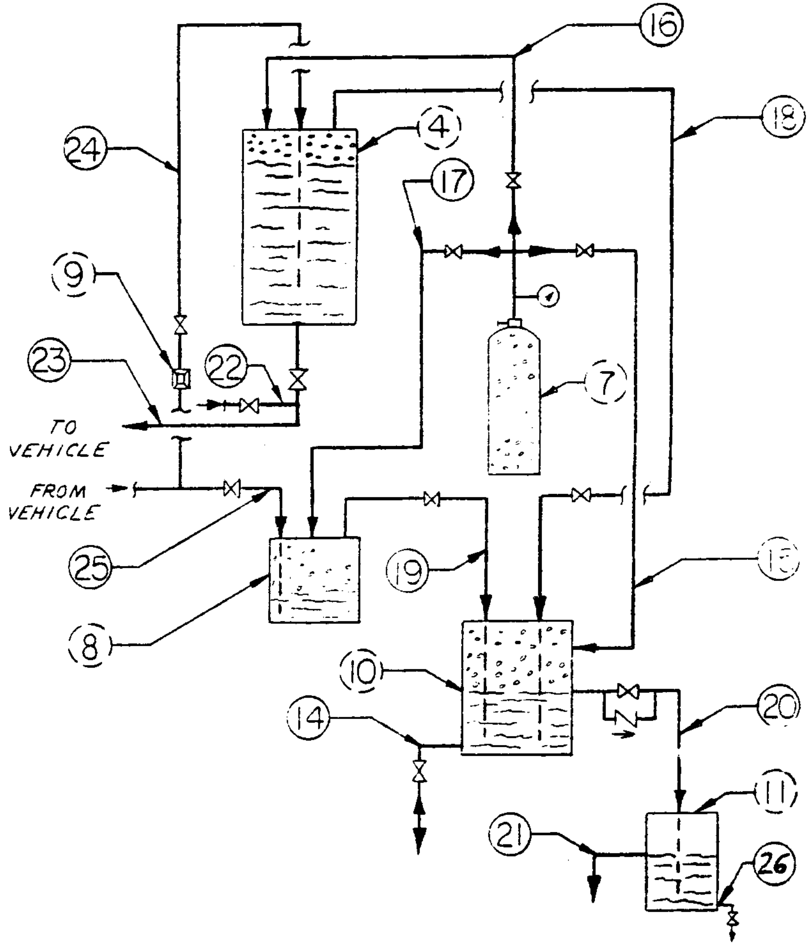

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FIGURE III

PROPELLANT PRESSURIZATION SYSTEM

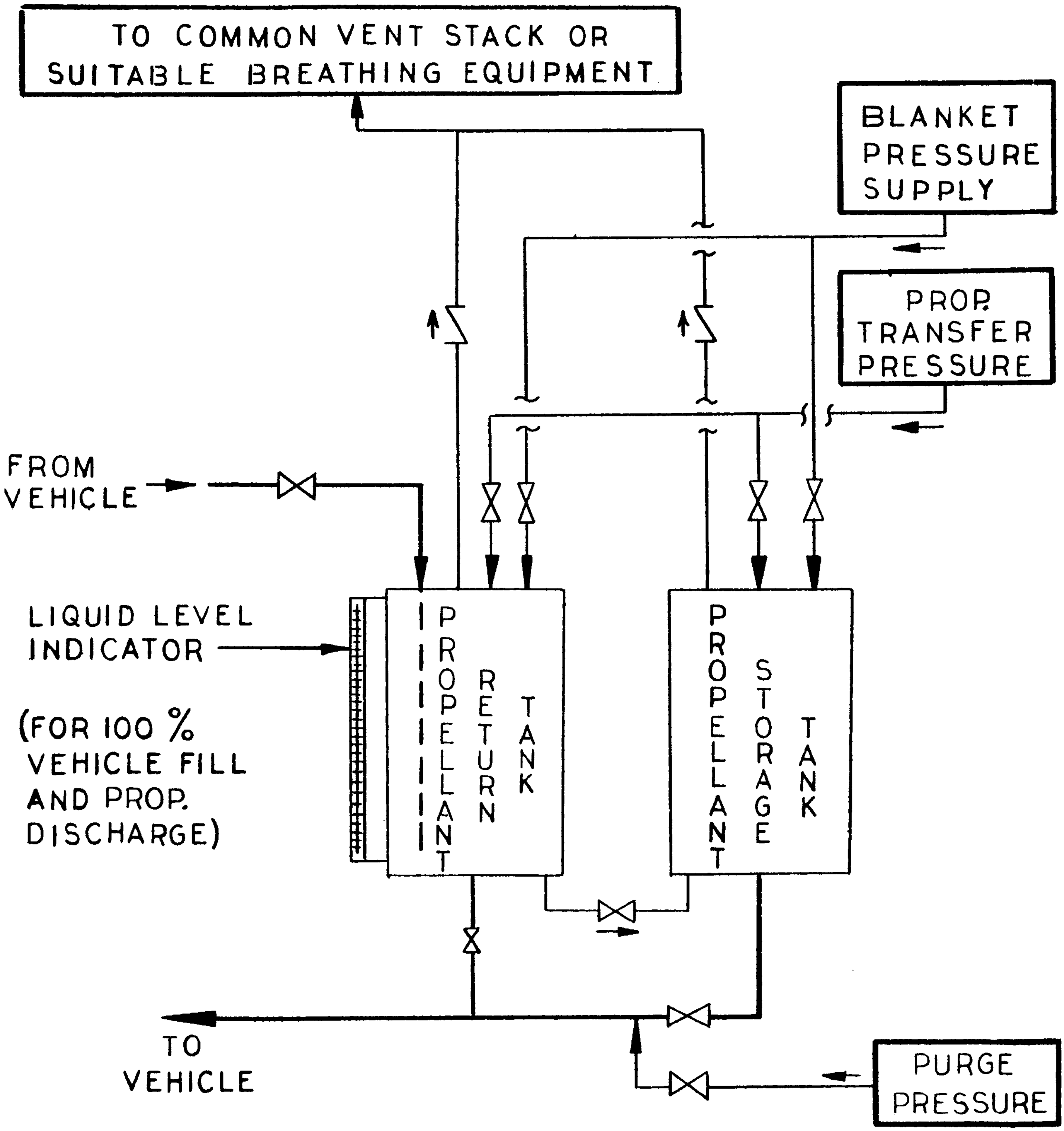


FIGURE IV

PROPELLANT DRUM STORAGE AND TRANSFER SYSTEM

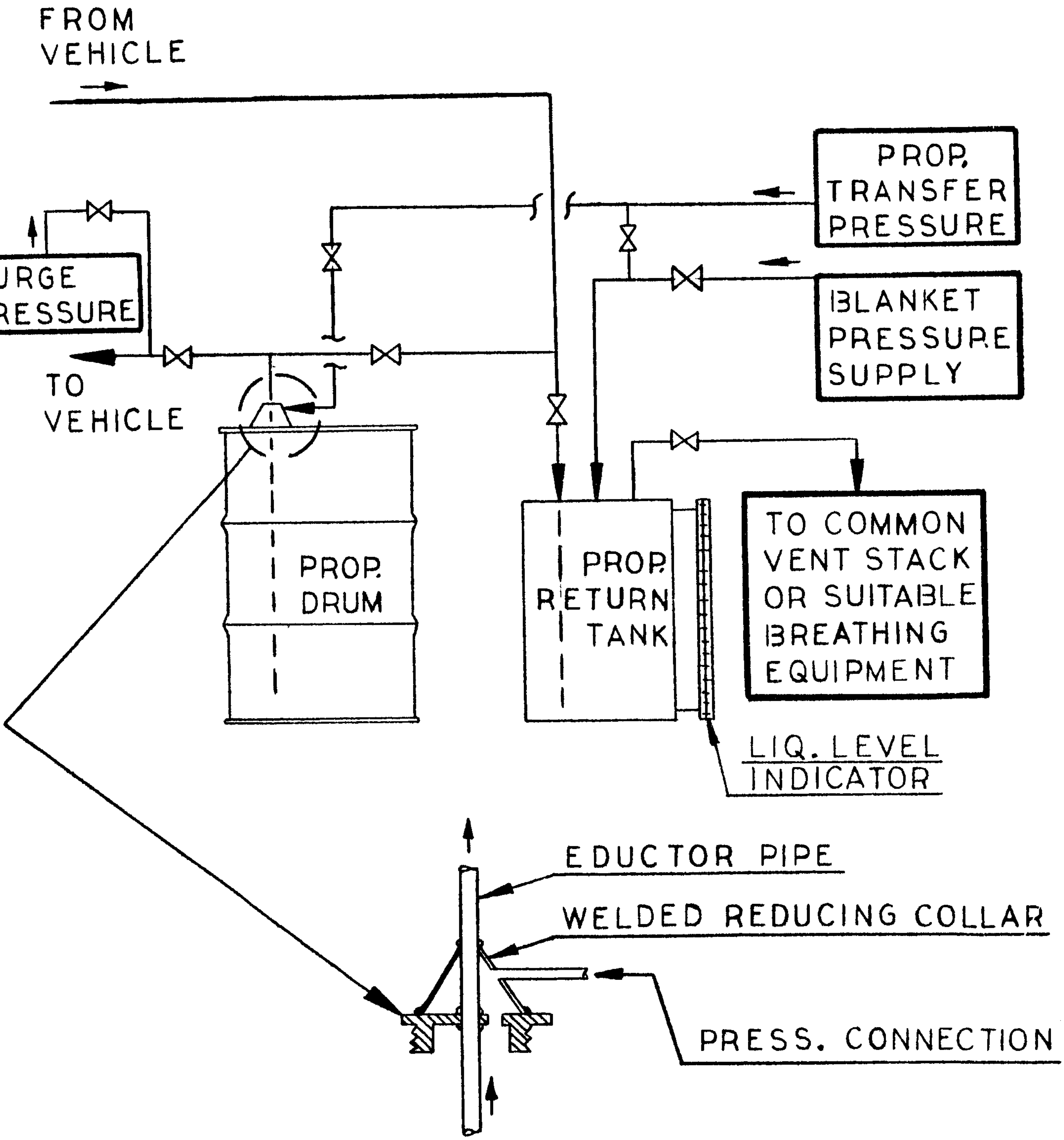
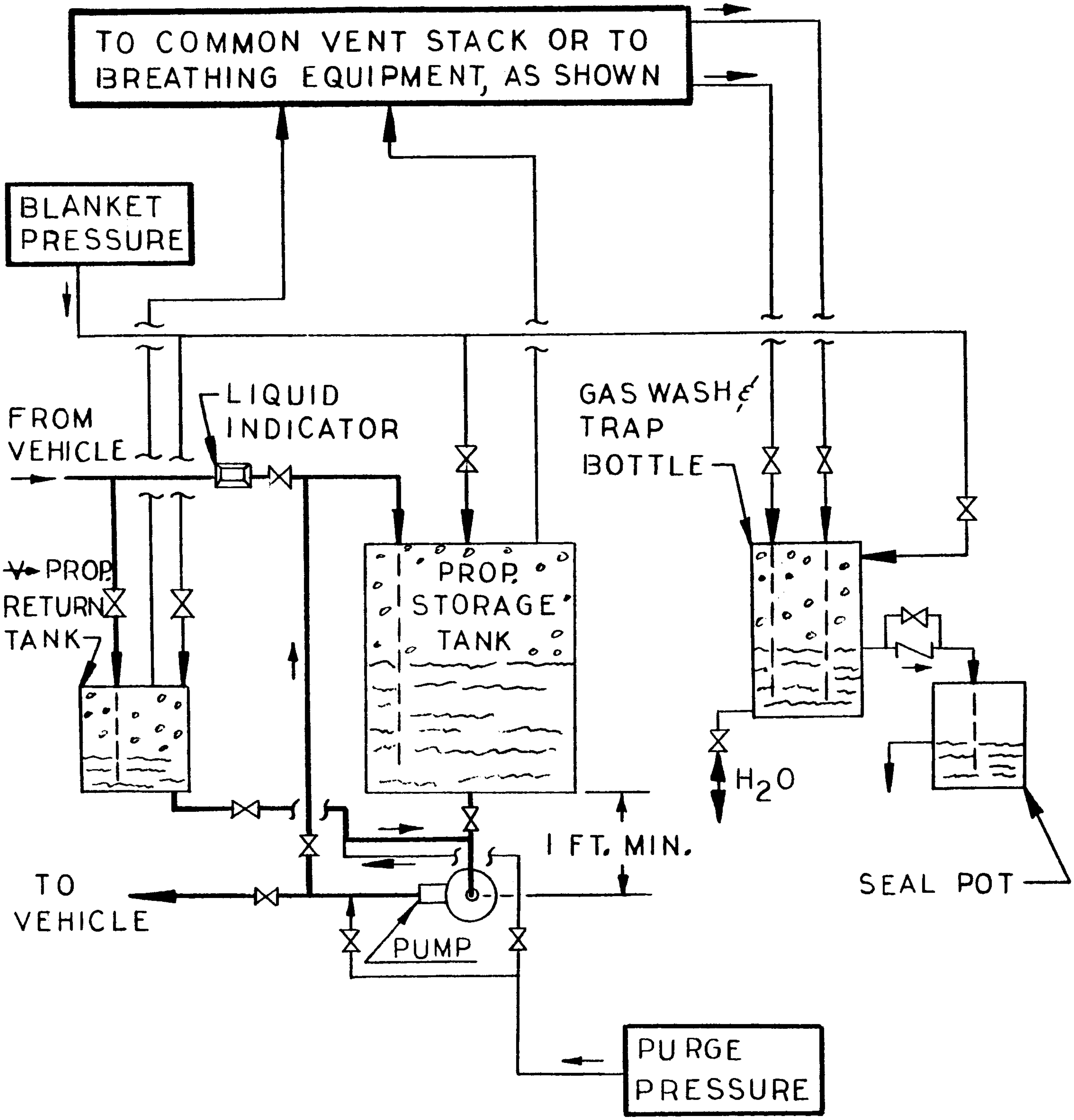


FIGURE V

PROPELLANT TRANSFER PUMP SYSTEM



GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

Memorandum

Mr. Foster, 876-0718

TO Mr. E. J. Field, M-SAT-S-II
Mr. J. McCullough, M-SAT-S-IVB

DATE June 11, 1962

FROM Chairman, M-SAT-WE
Chairman, M-SAT-WM

Memo No. M-P&VE-VG-84

SUBJECT S-II and S-IVB Umbilical Requirement for C-5.

REFERENCES (a) Unnumbered Memorandum from LOD, dated March 25, 1962, Subject: C-5 Umbilical Disconnect Prior to Holddown Release (Proposal).

(b) TWX #5256, dated June 6, 1962 from LOD.

1. On May 25, 1962, Launch Operations Directorate presented to Propulsion and Vehicle Engineering Division and Astrionics Division the problem incurred by keeping the present C-1 concept in the C-5 Program to releasing all umbilicals at first motion. This presentation is summarized in Reference (a).

2. Propulsion and Vehicle Engineering Division and Astrionics Division agrees with Launch Operations Directorate to the seriousness of the problem and tentatively agrees to the release of all swing arms prior to holddown release with the exception of Arms 4 and 6. This requires that all functions, both mechanical and electrical required to maintain the vehicle in a safe condition be brought out over Arms 4 and 6. It is assumed this will impose some weight penalty on the S-II and S-IVB Stages.

3. It is requested that SATURN Systems Office direct DAC and S&ID to make a study of required safing functions and any penalty imposed, so that, a final decision as to arm release times can be made. Reference (b) should be used as a guide to the types of function required for safing and monitoring the vehicle or stage. This information is required by July 1, 1962.

H. J. Fichtner

H. R. Palaoro

2 Enc: a/s

MSFC - Form 488 (August 1960)

Mr. Downs, 536-7421

May ~~23~~ 25, 1962

PRE-**PRESENTATION**

RTM

TO: ~~M-P&VE Division C-5 Meeting, May 23, 1962~~

FROM: Launch Facilities and Support Equipment Office, M-LOD-D

SUBJECT: C-5 Umbilical Disconnect Prior to Holddown Release (Proposal)

1. In a memorandum dated April 16, 1962, M-LOD-D (Mr. Herold) stated that it was "felt that consideration should be given to accomplishing and confirming operation of as many C-5 umbilical disconnects as possible before releasing holddowns and commitment of the vehicle to flight. This is particularly recommended in the case of cryogenic propellant lines and whatever other services that are no longer required for launch."

2. It was further stated, "Preliminary work on a C-5 Umbilical Study, currently in progress by M-LOD-DE, suggests that remote reconnect capability can be developed for many of the C-5 services and particularly LH_2 and LOX loading." Extracts from drafts of this study were attached as enclosures regarding the unreliability of the large number of in-flight disconnects currently required on C-5 launch.

3. The memorandum concluded, "M-LOD-DE believes that, with cooperation of stage contractors, many umbilical connections can be severed prior to flight and remote reconnect provided should the launch be aborted, thereby enhancing launch reliability."

4. It is the purpose of this presentation to clarify the principles of the proposal in order that they will not be misunderstood during your evaluation.

5. The present requirement is that C-5 umbilical arms will disconnect at lift-off. This requirement is based upon the need for maintaining "safing" control of the vehicle until the launch is committed beyond the point of abort capability. It is also felt that hydrogen propellant tank venting ducts should be maintained as a "safing" requirement until lift-off. It is not our intention that hydrogen vent ducts be included among the pre-holddown release disconnects.

6. The C-1 Booster, currently in flight test phase, employs an upper umbilical that disconnects approximately 20 seconds prior to lift-off. Disconnect and retraction are confirmed by feedbacks and launch would not be attempted with this umbilical stuck in the connected position. This principle should be carried over into the C-5 Booster with all "safing" circuits run through tail plugs that maintain connection with the launcher until separated by lift-off motion. This approach would allow complete separation, retraction, and confirmation of arm number two (reference Figure I).

7. Arm number one (Figure I) is placed for access to the intertank area of the S-IC and, if it carries no umbilicals, can certainly be retracted prior to lift-off. Umbilical services delegated to this arm under the present ruling would require the arm to remain in position until lift-off.

8. Arm number three carries electrical, pneumatic, propellant loading, and other services to the aft area of the S-II stage. The C-5 Umbilical Study, now in progress by M-LOD-DE, indicates that it is feasible to develop equipment for remote disconnect and reconnect of liquid hydrogen and liquid oxygen loading and unloading systems. Further discussion of this matter is contained in paragraphs 17, 18, and 19 of this presentation. Assuming for the moment that remote disconnect and reconnect propellant loading is attainable, as it appears to be, then there exists the possibility of eliminating the in-flight disconnect at this location by transferring all lift-off disconnects ("safing" functions) to the upper umbilical (arm number four) where the need for hydrogen vent ducting already requires an in-flight disconnect. A later paragraph (14) outlines the time sequencing of pre-flight and in-flight disconnects.

9. Arm number four serves to carry hydrogen vent ducting and services to the upper end of the S-II stage. As indicated in paragraph 8 above, it also should handle all "safing" functions for the S-II stage in order to allow disconnect and confirmation of arm number three. This arrangement makes necessary only one in-flight disconnect and retract risk required for the S-II stage.

10. Arm number five serves the lower area of the S-IVB stage with electrical, pneumatic, propellant, and miscellaneous services. Applying the logic of paragraph 8, above, all "safing" functions should be transferred to the upper umbilical (arm six) and remote reconnect provided for propellant detanking in event of an aborted launch. This would allow disconnect and confirmation of arm number five prior to release of vehicle holddowns.

11. Arm number six is required to be an in-flight disconnect because of the S-IVB hydrogen vent duct at that location, thus it is required regardless of whether or not "safing" functions are carried there. The use of safing functions through this arm would require only one (number six) arm to make an in-flight disconnect from the S-IVB. The "safing" of the R-2 stage should be handled through its lower umbilical which is also served from arm number six, requiring no additional arm for the R-2 lift-off disconnect unless the R-2 stage uses liquid hydrogen propellant. At the moment the question has not been settled whether cryogenic or storable (hypergolic) propellants will be used. If hydrogen venting is required, consideration should be given to venting by piping down to arm six or adding another arm and retract risk. This decision must necessarily adjudge a conflict which results in either reliability deterioration or weight penalty.

12. Only this week has NAA Apollo joined our Umbilical Task Force and began its contribution to the study. Subject to almost immediate change, Figure I shows the arms being considered to serve the service module (arm number eight) with the addition of two access platforms (arms seven A and

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eight A) used to afford egress and adjustment. The upper level is extremely crowded by the number of arms and platforms. It would alleviate the crowding greatly to combine the umbilical arms (seven and eight) with their respective access platforms (seven A and eight A). This would only be possible if the Apollo umbilicals are of the type suited to prelaunch release as the mass of the platforms negate rapid retraction following holddown release. Safing of the SM and CM stages if not accomplished by astronaut control, could be done, at some weight penalty, through the R-2 stage and arm number six which also "safes" R-2 and S-IVB stages.

13. Adoption of the principles of the foregoing paragraphs would allow the configuration of Figure II to be attained at the moment of holddown release. Note that only two arms are used for in-flight disconnects and the great risk entailed by holddown release while in Figure I configuration is greatly reduced.

14. The time sequencing of the events of launch under the conditions of Figure II are one key to the practicality of the system. All umbilicals (Figure III) would remain connected throughout engine ignition and up until thrust commit. At thrust commit, the command would be to disconnect all umbilicals not needed for "safing" the vehicle. Thus, at this point, arms numbers one, two, three, five, seven and eight would release and begin retraction. Upon receipt of "retract start" feedbacks from those arms, holddown release would be allowed. The remaining two arms, numbers four and six, would then be disconnected by vehicle lift-off motion at the point of no-abort.

15. Reconnecting Propellant Loaders:

a. With the sequence of paragraph 14, it is apparent that there is an interval of about one second or less in which the liquid hydrogen and liquid oxygen lines are disconnected with the possibility that they may be needed for detanking. This presents a need for remote reconnect of propellant lines. The extremely large and heavy disconnects for propellant loading of the S-II stage make it necessary to have a positive mechanical handling system to retract the disconnects instead of the usual lanyard snatch and catch design. The most direct mechanical handling system within the realm of our experience is in the LOX and fuel masts of the C-1 booster where, unknown to most people, remote push-button disconnect and reconnect actually exists. At this point you should see some motion pictures of a test of the C-1 LOX loading mast. The only person connecting and disconnecting the mast is the one pushing the button.

b. Motion Picture:

Scene	Shot	Content
1	Close	Title board
2	Long	LOX Mast, coupled, pumping, surfaces cold smoking
3	Medium	LOX Mast, coupled, drained but cold

Scene	Shot	Content
4	Close	LOX Mast, coupled, warm, disconnects and swings away
5	Close	LOX Mast, retracted, warm, coupling extends
6	Med Long	Test Area, operator at local control panel beside mast
7	Med Close	Local Control Panel and operator
8	Close	Operator, pushes button A
9	Close	LOX Mast, coupling retracts
10	Close	Operator, pushes button B
11	Close	LOX Mast, swing return to vehicle half
12	Close	Operator, pushes button C
13	Close	LOX Mast, couples to vehicle half
14	Long	Test Area, operator pushes button to disconnect
15	Med Close	LOX Mast, disconnects, swings back, head extends
16	Close	Title Board
17	Long	LOX Mast, disconnect without draining, ice fall, LOX spill, blockhouse control
18	Med Close	LOX Mast, disconnected, cold smoking, returns to vehicle and couples. Smoke cessation indicates sealing. Detanking begins.
19	Long	LOX Mast, normal speed (all previous shots slow motion) retraction in fraction of a second, without draining, LOX spill.

c. It is forseen that the principles you just saw on C-1 masts could be employed to provide remote disconnect and reconnect of propellant lines to the vehicle from an umbilical arm as surely as they do at the present from the launcher.

16. The development of recoupling propellant loaders for upper stages appears feasible. M-LOD-DE recommends that such a development be authorized and would like to assure that it would not be wasted effort when the hardware is built. To this end, umbilical systems should be planned so that they do not prevent the application of such reconnecting systems while the development program is in progress. There are a number of problems involved in

disconnecting and reconnecting cryogenic lines, hydrogen in particular. The following paragraph outlines some of the problem areas that need investigating.

17. Neither liquid oxygen nor liquid hydrogen disconnects are severed until after the fluids have been drained and the interior purged to completion with inert gas. Upon disconnection, frost occurs on cold sealing surfaces. In the case of LOX, experience has indicated no difficulty in obtaining a resealing, as you saw in the film. With liquid hydrogen, no such experience background exists that would serve to determine if liquid air condensation on the disconnect or other difficulty is encountered. Procedures for protecting disconnects (annular nozzle purges, protective boots, heating, decontaminating, etc.) must be investigated. Also required are connecting devices that will "chase" the vehicle half and couple to it. There are several approaches to that problem presently being considered that overcome the relative sway motion between vehicle and umbilical arm. The return swing motion and reindexing of arm position toward the vehicle for reconnecting is considered an easily obtained action.

18. A simple two-plane chase will serve to locate and couple with the swaying vehicle connector half. Figure IV illustrates the first chase plane. As the arm is rotated back toward the vehicle following an aborted launch, a feeler wheel is extended. The wheel then rides the skin and locks on a vertical tee-bar. The position of the feeler serves to orient the up-tilted propellant masts, either by controlling the arm position, or more simply, by a direct linkage with the masts themselves. Reference to Figure V shows an analagous chase in the vertical plane as the propellant mast is lowered. The extendable coupling end is guided into place by a vee which straddles the vehicle half. The final coupling seal is obtained by a pressure coupling similar to the C-1 mast. The thrust placed into the vehicle half by the pressure is removed through the vee straddling the vehicle half. Following completion of the coupling the feeler is unlocked and retracted. Draining of propellants can then proceed following a decontamination purge and chilldown.

19. To remove the vehicle disconnect half from the inflight airstream it may be coved into the skin as indicated by Figures VI and VII. The coupling procedure is identical with the paragraph above with the additional refinement of introducing vertical sensing of coupling position by a dual ramp which confines the feeler wheel to a specific vehicle station at lock-on.

20. Techniques for remote control should be as simple as possible and rely strongly on mechanical devices to increase the reliability of operations. Even the best systems will fail, and a reconnect failure can be expected sometime. Should this happen, then the vehicle will remain tanked with propellants until they safely boil away through the vents. The hydrogen vent ducting is still coupled, and this is a thoroughly safe, although time consuming expedient.

21. To summarize: It is felt that consideration should be given to accomplishing and confirming operation of as many C-5 umbilical disconnects as possible before commitment of the vehicle to flight. M-LOD-DE believes that the large number of components that must operate successfully after

holddown release can be drastically reduced and launch reliability greatly increased by adopting this proposition.

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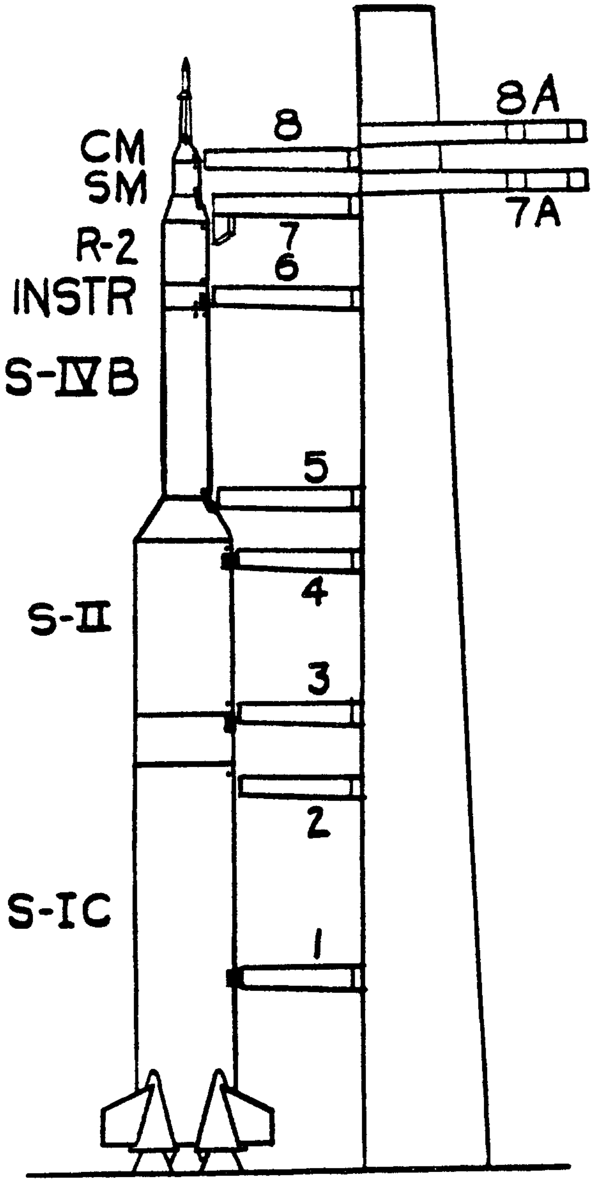

FIG. I

• UMBILICAL
■ ACCESS DOOR

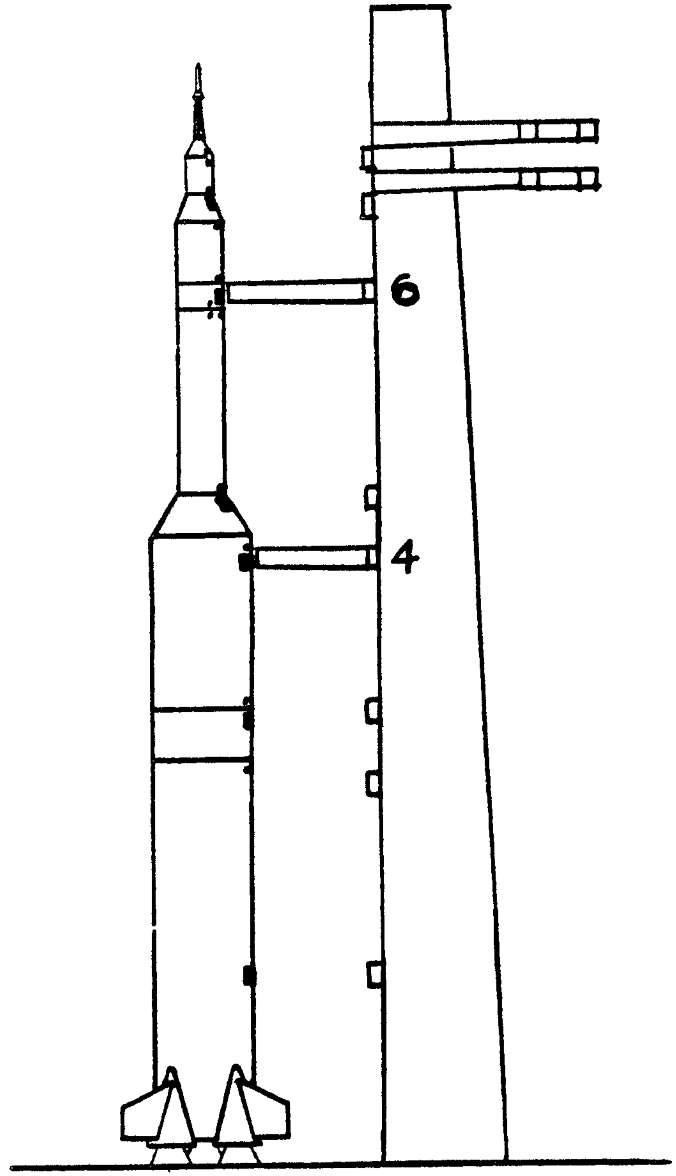

FIG. II

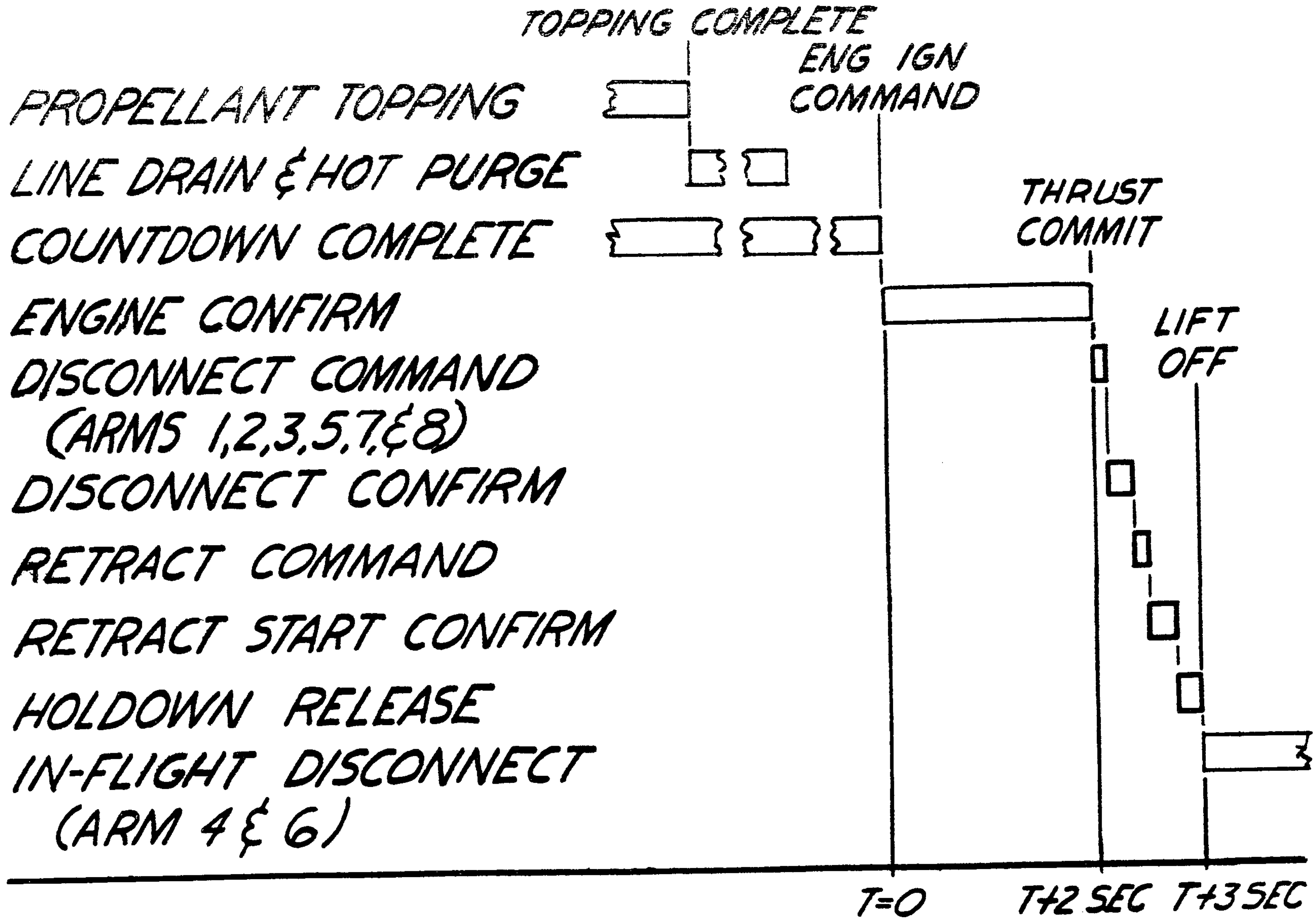
TOPPING COMPLETE
ENG IGN COMMAND
PROPELLANT TOPPING
LINE DRAIN & HOT PURGE
THRUST COMMIT
COUNTDOWN COMPLETE
ENGINE CONFIRM
LIFT OFF
DISCONNECT COMMAND (ARMS 1,2,3,5,7,& 8)
DISCONNECT CONFIRM
RETRACT COMMAND
RETRACT START CONFIRM
HOLDOWN RELEASE
IN-FLIGHT DISCONNECT (ARM 4 & 6)
T=0
T+2 SEC
T+3 SEC

FIG. III

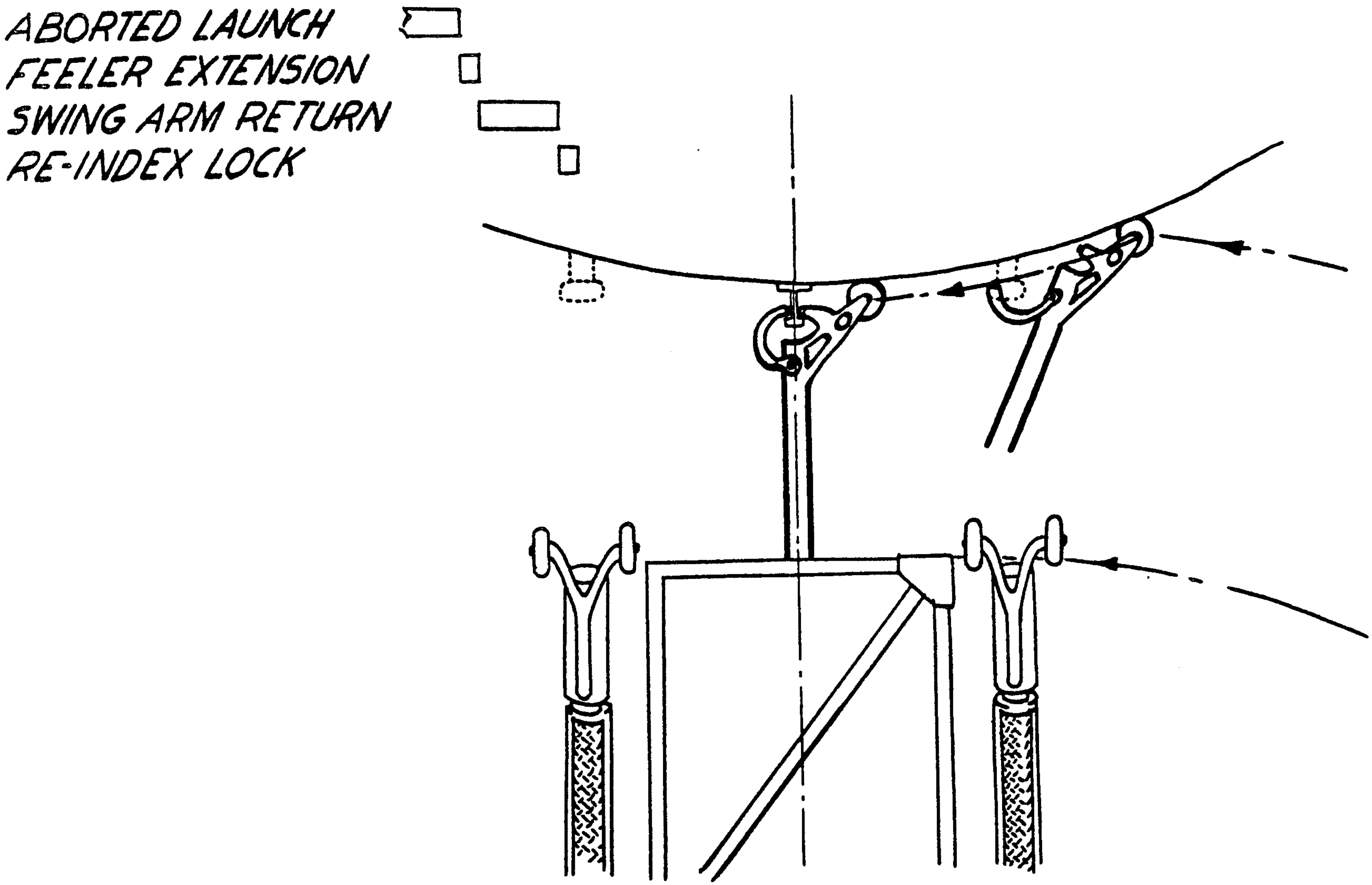
ABORTED LAUNCH
FEELER EXTENSION
SWING ARM RETURN
RE-INDEX LOCK

FIG. IV

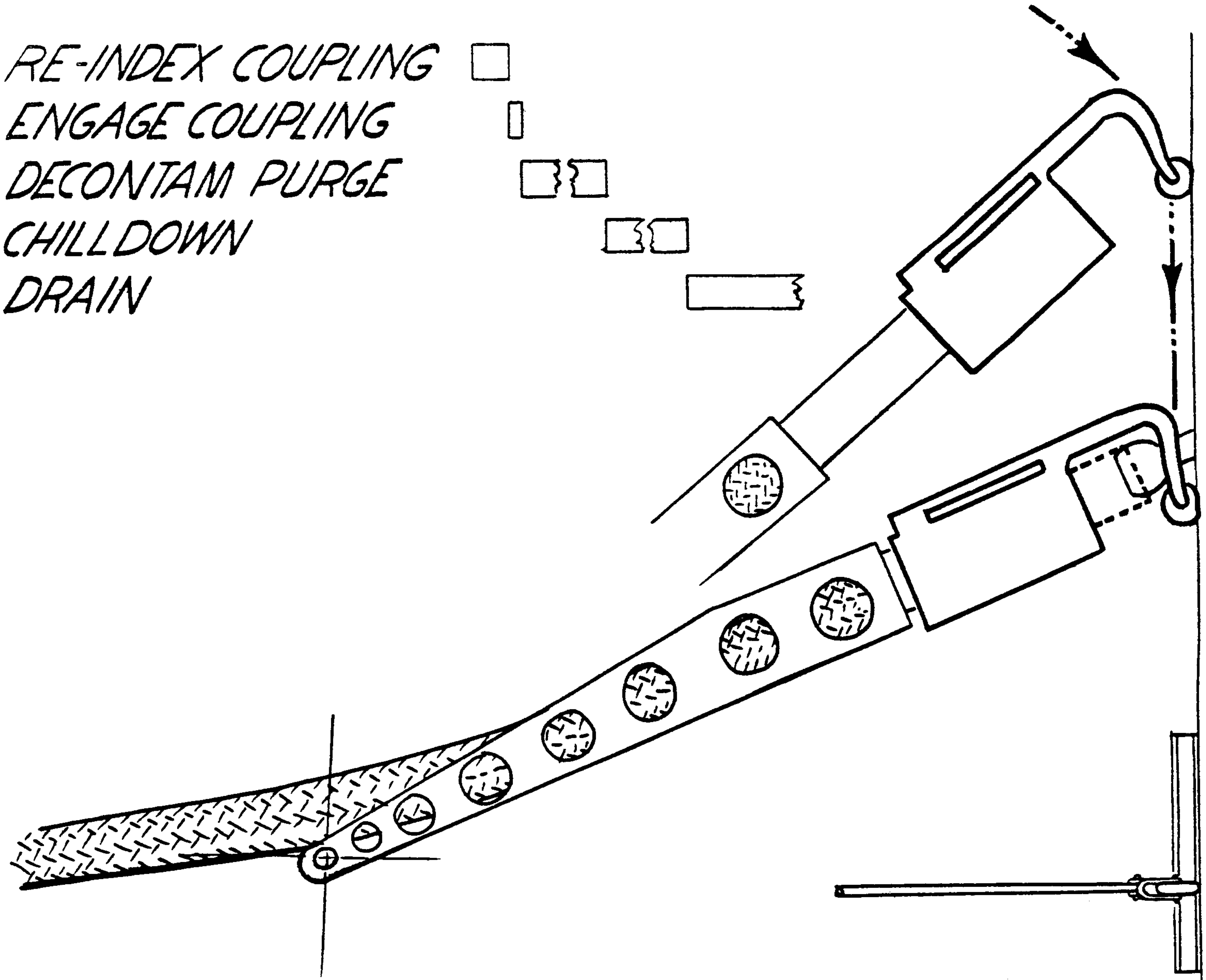
RE-INDEX COUPLING
ENGAGE COUPLING
DECONTAM PURGE
CHILLDOWN
DRAIN

FIG. V

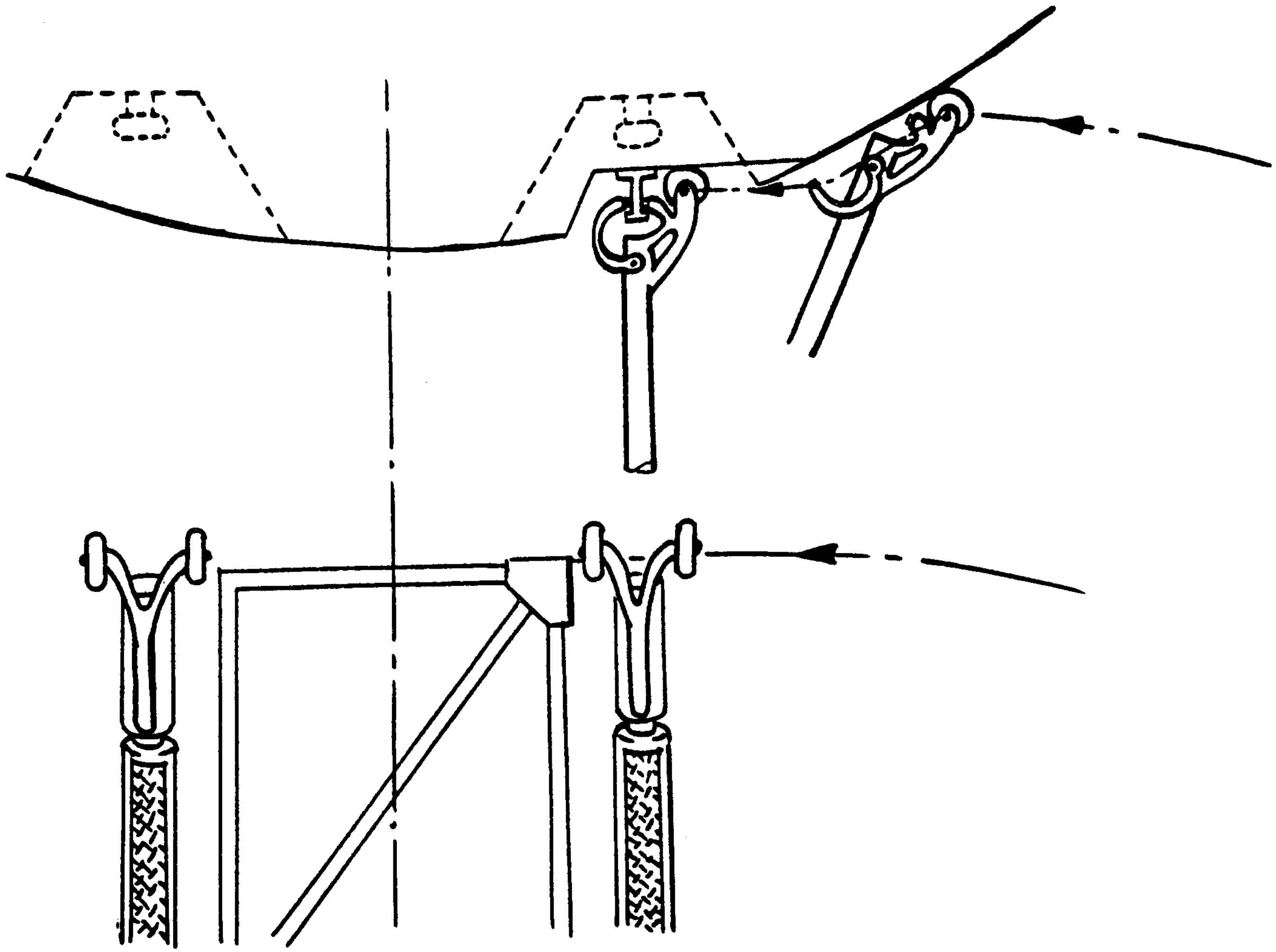

FIG. VI

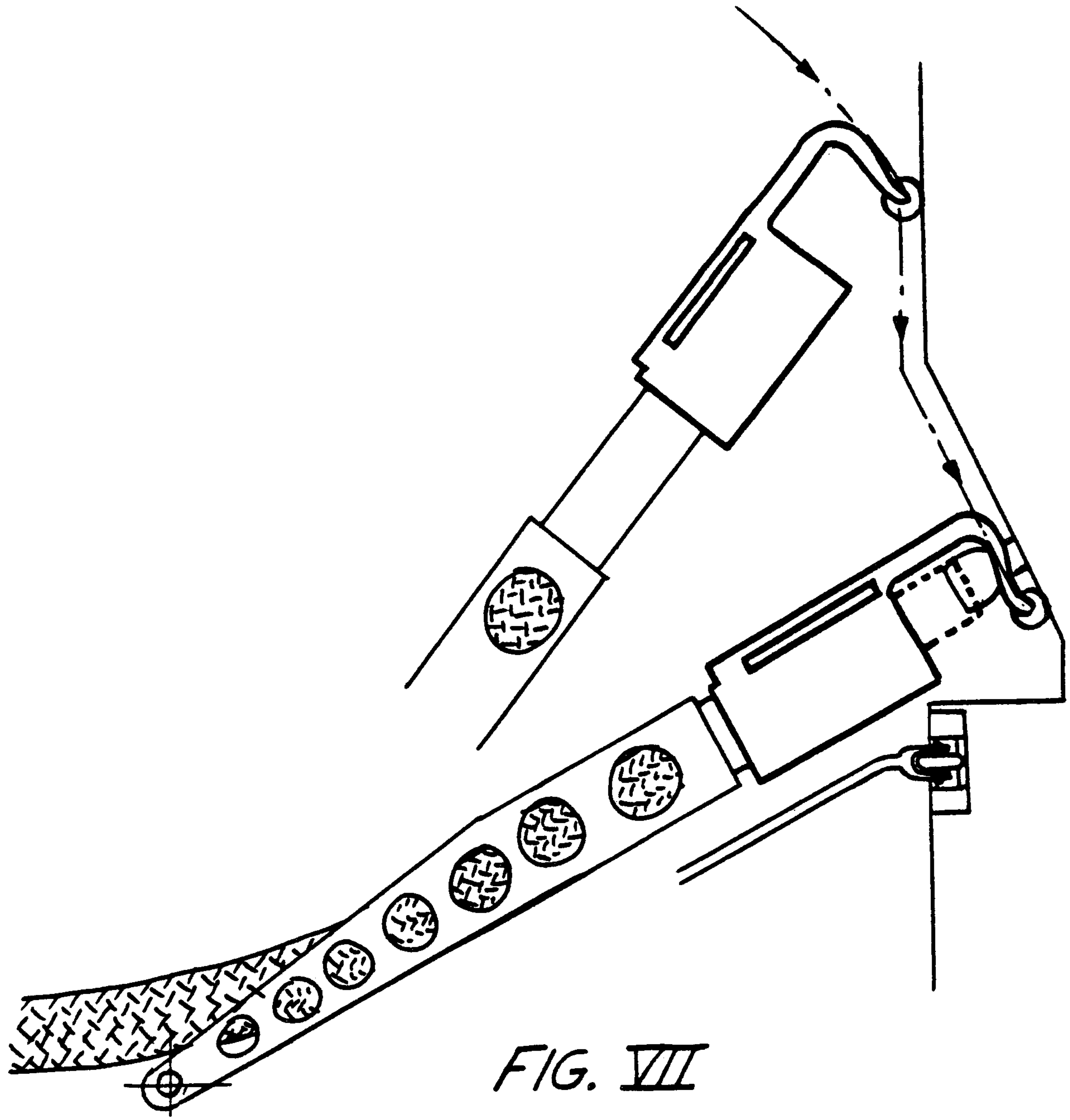

FIG. VII

GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

Memorandum

Mr. McCullough, 876-4319

TO

DATE July 19, 1962

FROM Chief, Vehicle Systems Integration Office, M-P&VE-V

M-P&VE-VG-107

SUBJECT S-II and S-IVB Umbilical Requirements for C-5.

REFERENCE Memorandum M-P&VE-VG-84, dated June 11, 1962, Subject: S-II and S-IVB Umbilical Requirements for C-5.

1. A portion of the information requested in the above reference has been received by this Office and is forwarded for information and consideration.

2. The portion still missing as requested from Douglas Aircraft Company, Inc., is expected by July 20, 1962 and will be forwarded when received.

3. Upon receipt of Douglas Aircraft Company input, this Office will call a meeting in order to firm up umbilical safing requirements for Marshall Space Flight Center.

H. R. Palaoro

H. R. Palaoro

1 Enc:
NAA Memo, dtd July 2, 1962,
Subj: Umbilical Requirements
for SATURN C-5.

NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION

INTER-OFFICE LETTERS ONLY S-II/SE 62-161

RECEIVED JUL 13 1962

TO	D. R. Bowden	DEPARTMENT	NASA Rep.
FROM	P. L. Wickham	DEPARTMENT	4595-01
PHONE	2259	DATE	2 July 1962

SUBJECT Umbilical Requirements for Saturn C-5

Reference (a) M-SAT-S-II 61-62 Umbilical Requirements for C-5, 18 June 1962

This IOL is in response to the reference (a) letter, from E. L. Field to D. R. Bowden requesting comments from S&ID in regard to the LOD proposed umbilical release scheme for the Saturn C-5 Vehicle. The present concept is to release all umbilical connections at LIFT OFF. The proposed concept involves the release of all umbilical connections one second prior to LIFT OFF with the exception of tail connections on S-IC, Umbilical-Arm #4 located at the top of the S-II stage, and Umbilical Arm #6 located at the top of the S-IVB stage. This change will require that all S-II stage "safing" functions be located on Umbilical Arm #4.

S&ID comments are based upon the assumption that in the event of an abort during the one second interval between THRUST COMMIT (T + 2 SEC.) and LIFT OFF (T + 3 SEC.) the abort will be complete. The C-5 vehicle will be completely detanked of cryogenics permitting access to the stages by personnel in order to re-service systems prior to re-initiating countdown.

S-II payload weight penalties incurred by transferring certain "safing" functions from Umbilical Arm #3 to Umbilical Arm #4 can be approximated in the electrical area at this time. Weight penalties incurred in the structures area require additional design study based upon detailed information from MSFC concerning the remote reconnect mechanism to be used.

S&ID is at this time ready to prepare the procurement specification for the S-II disconnects. Changing to the remote reconnect concept will result in a loss of considerable design effort to date.

Comments are presented in the electrical and structures areas as follows:

Electrical System

1. Ground power and power control for the instrumentation and emergency d-c buses is routed through the upper umbilical. (No change required.)

2. Auxiliary ground power and power control for the main d-c bus would be required through the upper umbilical. These requirements would include power leads, regulator sensing, power transfer switch control and position monitor. Power requirements for the main d-c bus through the upper umbilical would be approximately 1600 watts. Weight increase for these requirements would be approximately 70 pounds. The possibility also exists that two additional relays would be required for transfer control.

3. Additional wire may be needed to power various a-c heaters through the upper umbilical.

4. Additional power plug and receptacle would be required increasing stage weight approximately 14 pounds.

5. Certain electrical control system functions would be required thru the upper umbilical arm. These functions are listed as follows:

   a. A solenoid electrical control for LOX fill and drain valve — 1 wire

   b. Valve position information for LOX valve-open or closed — 2 wires

   c. Solenoid electrical control for fuel fill and drain valve — 1 wire

   d. Valve position information for fuel valve-open or closed — 2 wires

   e. Hydrogen vent valve electrical control — 1 wire

   f. Hydrogen vent valve position-open or closed — 2 wires

   g. Solenoid electrical control for LOX vent valve to permit backflow purging of LOX tank — 1 wire

   h. LOX vent valve position-open or closed — 2 wires

   i. Separation system electrical control — 4 wires

6. The LOC proposal does increase the complexity of both the ground and stage systems; however, the changes can be incorporated with a weight penalty of approximately 91 pounds (Ref. Items 2, 4 and 5). An additional 38 wires would be required through the upper umbilical system.

Structures

1. The existing umbilical disconnect panel will require revision to accommodate the electrical changes.

2. The systems tunnel will probably require enlargement to accommodate the additional wiring. The larger tunnel will affect a greater number of stringers and require revision of the AFT SKIRT structure to accommodate the changes in the tunnel.

3. In the event purging of the umbilical disconnect panel becomes necessary (to allow for remote reconnect), complete redesign of the panel mounting structure will be necessary.

4. Stops and guides for vertical and horizontal indexing for the remote reconnect mechanism will be required. In addition, back up structure capable of reacting the remote reconnect forces must be added.

5. Present S-II design includes external vertical stringers in the area of the existing umbilical disconnects. The skin and stringers will require revision to provide the necessary flat surface for the remote reconnect mechanism.

If the present umbilical design concept is to be changed, it is a matter of extreme urgency. Contractor re-direction is required as early as possible to minimize program schedule delays.

R L Moore
for P. L. Wickham
Chief Engineer
S-II Engineering

PLW:EGL:cp

cc: S-II Managers
S-II Engineering Managers

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MR. J. C. MCCULLOCH, M-SAT, PROJECT MANAGER SATURN
STAGE S-IVB
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

DOUGLAS AIRCRAFT COMPANY, INC., T. D. SMITH
W. F. SHAVER, M-SAT, DAC REP.,
HUNTSVILLE INDUSTRIAL CENTER,
BLDG. 3 ROOM 113
HUNTSVILLE, ALABAMA
G. J. STOOPS, NASA/MSFC RESIDENT REP. (WE SEND)
J. MAZUR, NASA/WOO 150 PICO BLVD.,
SANTA MONICA, CALIFORNIA
O. S. TYSON, NASA/MSFC RESIDENT REP. AT A45,
SACRAMENTO, CALIFORNIA
H. R. PALAORO, NASA/MSFC, P&VE
H. J. FICHTNER, NASA/MSFC, M-ASTR
R. GRINER, NASA/MSFC, M-P&VE
R. EARNES, NASA/MSFC, M-P&VE

TECHNICAL COORDINATION BULLETIN NO. S-IVB-2

IN REPLY REFER TO: A2-260-SAT-155

SUBJECT: S-IVB UMBILICAL REQUIREMENTS FOR C-5
(UMBILICAL SAFING STUDY)

THIS STUDY WAS EXECUTED TO PROVIDE A COMPARISON SHOWING THE VEHICLE WEIGHT PENALTY ASSOCIATED WITH VARIOUS METHODS OF UMBILICAL RETRACTION. THE FOLLOWING CASES ARE PRESENTED FOR YOUR REVIEW PRIOR TO YOUR CONCLUSIONS NECESSARY TO DIRECT OUR STAGE DESIGN.

ASSUMPTIONS:

CASE I

1. USE S-IVB DESIGN AS PROPOSED; THAT IS A DESIGN CONCEPT SIMILAR TO THAT USED ON S-IV.

2. ALL UMBILICALS DISCONNECT AFTER LIFTOFF HAS BEEN CONFIRMED.

   NOTE: THIS SYSTEM ALLOWS OPTIMUM ROUTING WITHIN THE VEHICLE OF ALL UMBILICAL FUNCTIONS, THEREFORE, IT IS THE LOWEST WEIGHT CASE AND IS USED AS A STANDARD FOR COMPARISON FOR CASE II AND III.

CASE II

1. RETAIN EXISTING S-IVB DESIGN CONCEPTS AS FAR AS POSSIBLE.
2. RETRACT UPPER UMBILICAL ARM AFTER LIFTOFF CONFIRMATION.
3. RETRACT LOWER UMBILICAL ARM A FEW SECONDS PRIOR TO LIFTOFF.
4. NO REQUIREMENT TO REMOTELY RECONNECT THE LOWER UMBILICAL ARM.
5. IF ABORT OCCURS AFTER THE LOWER UMBILICAL IS RETRACTED, PROPELLANT UNLOADING IS NOT REQUIRED.

6. ALL FUNCTIONS REQUIRED FOR SAFETY OF VEHICLE AND/OR TO DETERMINE THAT THERE IS NO UNSAFE CONDITION ARE RE-ROUTED THROUGH THE FORWARD UMBILICAL ARM.

CASE III

1. RETAIN EXISTING DESIGN AS FAR AS POSSIBLE FOR THE FORWARD UMBILICAL ARM.
2. RETRACT LOWER UMBILICAL A FEW SECONDS PRIOR TO LIFTOFF AND PROVIDE THE CAPABILITY TO REMOTELY RECONNECT THE LIQUID HYDROGEN, LOX, AND AIR CONDITIONING LINES.
3. RE-ROUTE ALL SAFING FUNCTIONS TO FORWARD UMBILICAL AS IN ITEM 6 OF CASE II ABOVE PLUS THOSE FUNCTIONS REQUIRED TO UNLOAD CRYOGENICS.
4. MANUALLY RECONNECT THE REMAINING AFT UMBILICAL FUNCTIONS AFTER UNLOADING CRYOGENICS; THAT IS, HYPERGOLICS AND MISCELLANEOUS ELECTRICAL CONTROLS AND INDICATIONS.
5. NO STRUCTURAL WEIGHT PENALTIES ARE INCLUDED FOR REMOTE RECONNECT CAPABILITY; THAT IS, THOSE WEIGHTS ASSOCIATED WITH THE SENSING-LOCATING

DEVICE AND ADDED STRUCTURE TO TAKE THE INDUCED LOADS OF THE RECONNECTION MECHANISMS.

RESULTS - VEHICLE WEIGHT PENALTIES:

CASE I - WEIGHT PENALTY - BASIC WEIGHT

CASE II - BASIC WEIGHT PLUS 121 LBS

CASE III - BASIC WEIGHT PLUS 143 LBS PLUS ADDITIONAL UNKNOWN STRUCTURAL WEIGHT PENALTY NOTED IN ITEM 5, CASE III.

VALID STRUCTURAL WEIGHT PENALTIES COULD NOT BE DETERMINED AS THE FORCES RESULTING FROM THE RECONNECT MECHANISM ARE UNKNOWN. IT IS ANTICIPATED THAT THE SATURN SYSTEMS OFFICE WILL AUTHORIZE A STUDY TO DEVELOP A RECONNECT MECHANISM DESIGN AS A RESULT OF THE LOD WORKING GROUP MEETING ON JULY 18 AND 19. THE RESULTS OF THIS STUDY WILL ALSO INCLUDE THE VEHICLE STRUCTURAL WEIGHT PENALTIES.

A CHART SHOWING THE DETAILED RESULTS OF THIS STUDY HAS BEEN PREPARED AND WILL BE MAILED IMMEDIATELY.

THIS CHART SHOWS THE DETAILED UMBILICAL FUNCTIONS, THE UMBILICAL THROUGH WHICH THEY ARE ROUTED AND THE WEIGHT PENALTY ASSOCIATED WITH EACH CASE.

ORIGINAL SIGNED BY
A. P. O'NEAL

COMPARISON STUDY
UMBILICAL SAFING
SIVB UMBILICAL REQUIREMENT FOR CS

REF 75M-02959L

CASE I (BASIC) UPPER AND LOWER UMBILICAL DISCONNECT AT VEHICLE LIFTOFF MINIMUM VEHICLE WEIGHT CONDITION				CASE II UPPER UMBILICAL DISCONNECTS AT VEHICLE LIFTOFF LOWER UMBILICAL DISCONNECTS PRIOR TO VEHICLE LIFTOFF. NO REMOTE RECONNECT, PROPELLANTS ALLOWED TO BOILOFF OR POSSIBILITY OF MANUAL RECONNECT			CASE III UPPER UMBILICAL DISCONNECTS AT VEHICLE LIFTOFF LOWER UMBILICAL DISCONNECTS PRIOR TO VEHICLE LIFTOFF RECONNECT OF LOX, LH_2 & AIR CONDITIONING LINES ONLY PROVIDED TO DEFUEL		
FIND NO	UMBILICAL	FUNCTION	UMBILICAL POSITION	REQD TO SAFE	REASON	PENALTY	REQD TO SAFE	REASON	PENALTY
1	LOX	LOX FILL & DRAIN	AFT	NO	—	—	YES (RECONNECTED)	TO DRAIN LOX TANK	UNKNOWN
2	LH_2	LH_2 FILL & DRAIN	AFT	NO	—	—	YES (RECONNECTED)	TO DRAIN LH_2 TANK	UNKNOWN
3	FUEL PREPRESS	LH_2 TANK PRE-PRESS (BEFORE FLIGHT)	AFT	NO	—	—	YES REROUTE TO FWD	PRESSURE TO DRAIN LH_2 TANK	*
4	COLD HE BOTTLES	LOX TANK PRE-PRESS	AFT	NO	—	—	YES REROUTE TO FWD	PRESSURE TO DRAIN LOX TANK	*
5	VALVE ACTUAT	LH_2 & LOX FILL & DRAIN VALVES LH_2 & LOX VENT VALVES	AFT	YES REROUTE TO FWD	HE PRESSURE TO OPERATE VENT VALVES	*	YES REROUTE TO FWD	HE PRESSURE TO OPERATE LOX & LH_2 FILL & DRAIN AND VENT VALVES	*
6	LOX PUMP SEAL PURGE	LOX PUMP PURGE	AFT	NO	—	—	NO	—	—
7	LH_2 PUMP SEAL PURGE	LH_2 PUMP PURGE	AFT	NO	—	—	NO	—	—
8	TURBINE START BOTTLE VENT ACTUAT	TURBINE START BOTTLE VENT VALVE	AFT	YES REROUTE TO FWD	HE PRESS TO OPERATE TURBINE START BOTTLE VENT VALVE	*	YES REROUTE TO FWD	AS FOR CASE II	*
9	TURBINE START BOTTLE COLD GH_2 SUPPLY	FILLS TURBINE START BOTTLE	AFT	NO	—	—	NO	—	—
10	COLD HE BOTTLE SUPPLY	FILLS ENGINE HELIUM BOTTLE	AFT		—	—	NO	—	—
11	ELECT	VARIOUS	AFT		—	—	NO	—	—
12	AIR CONDITIONING	AIR CONDITIONS AFT INTERSTAGE	AFT		—	—	YES (RECONNECTED)	TO PURGE AFT INTERSTAGE AREA DURING DEFUELING	UNKNOWN
31	COLD H_2 SUPPLY	FUEL TANK RE-PRESS (IN FLIGHT)	AFT		—	—	NO	—	—
32	ENG GAS GEN COOLDOWN LOX	PRE LAUNCH COOLDOWN OF GAS GENERATOR LOX	AFT		—	—	NO	—	—
33	ENG GAS GEN COOLDOWN LH_2	PRE LAUNCH COOLDOWN OF GAS GENERATOR LH_2	AFT	NO	—	—	NO	—	—
34	ENG GAS GEN COOLDOWN LH_2 VENT	VENT FOR PRE-LAUNCH COOLDOWN LH_2	AFT	YES REROUTE TO FWD	TO VENT GH_2 FROM ENG GAS GEN COOLDOWN TO DISPOSAL AREA	*	YES REROUTE TO FWD	AS FOR CASE II	*
35	TURBINE SEAL BLEED	VENT FOR COOLDOWN LH_2 SEAL LEAKAGE	AFT	NO	—	—	NO	—	—
36	TURBINE START BOTTLE RELIEF	VENT FROM TURBINE START BOTTLE RELIEF VALVE	AFT	YES REROUTE TO FWD	VENT GH_2 FROM TURBINE START BOTTLE RELIEF VALVE TO DISPOSAL AREA	*	YES REROUTE TO FWD	AS FOR CASE II	*
37	TURBINE START BOTTLE VENT	VENT FROM TURBINE START BOTTLE	AFT	YES REROUTE TO FWD	VENTS GH_2 FROM TURBINE START BOTTLE TO DISPOSAL AREA	*	YES REROUTE TO FWD	AS FOR CASE II	*
38	COLD GH_2 BOTTLE VENT	VENT FROM COLD GH_2 BOTTLES	AFT	YES REROUTE TO FWD	VENTS GH_2 FROM COLD GH_2 BOTTLES TO DISPOSAL AREA	*	YES REROUTE TO FWD	AS FOR CASE II	*
21	GH_2 VENT	LH_2 TANK VENT	FWD	YES	VENTS GASEOUS HYDROGEN TO A DISPOSAL AREA DURING BOIL OFF	NOT APPLICABLE	YES	AS FOR CASE II	NOT APPLICABLE
22	NOT USED								
23	ELECT	REQD. TO SAFE VEHICLE	FWD	YES	TO MONITOR AND MAINTAIN CONTROL OF THE VEHICLE	48 POUNDS	YES	AS FOR CASE II	52 POUNDS
13	(HYP FUEL) TRANSFER LINE PURGE	PURGE FOR HYP FUEL FILL LINE	AFT	NO	—	—	NO	—	—
14	(HYP OXID) TRANSFER LINE PURGE	PURGE FOR HYP OXID FILL LINE	AFT		—	—		—	—
15	(HYP FUEL) FILL	SELF EXPLANATORY	AFT		—	—		—	—
16	(HYP FUEL) RETURN	SELF EXPLANATORY	AFT		—	—		—	—
17	HE PRESS FILL	FILL FOR HE BOTTLE TO PRESS. HYP FUEL & OXID TANKS	AFT		—	—		—	—
18	(HYP OXID) RETURN	SELF EXPLANATORY	AFT		—	—		—	—
19	(HYP OXID) FILL	SELF EXPLANATORY	AFT		—	—		—	—
20	(HYP OXID) TANK VENT	SELF EXPLANATORY	AFT		—	—		—	—
30	(HYP FUEL) TANK VENT	SELF EXPLANATORY	AFT		—	—		—	—
NEW	LH_2 SEAL PURGE - FUEL SEAL CAVITY	PREVENTS LH_2 FROM ENTERING TURBINE	AFT	NO	—	—	NO	—	—
					* PROPULSION TOTAL ELECTRICAL	73 POUNDS 48 " 121 POUNDS		* PROPULSION TOTAL ELECTRICAL	91 POUNDS 52 143 POUNDS

MOMENTS OF INERTIA OF C-5 VEHICLE

FOR THIN SHELL $A = 2\pi r t$
$I = \pi r^3 t$

$$I = \pi r^3 \left(\frac{A}{2\pi r}\right) = \frac{r^2 A}{2}$$

A. BELOW TANKS - S1-C

$$I = \frac{(198)^2 (715)}{2} = \frac{(19{,}600)(715)}{2} = 14.0 \times 10^6$$

B. RP-1 TANK - S1-C

$$I = (19{,}600)(329) = 6.45 \times 10^6$$

C. INTERTANK SECTION - S1-C

$$I = (19{,}600)(239) = 4.68 \times 10^6$$

D. LOX TANK - S1-C

$$I = (19{,}600)(329) = 6.45 \times 10^6$$

E. INTERSTAGE SECTION - S1-C

$$I = (19{,}600)(259) = 5.07 \times 10^6$$

F. APORN AREA - S-II

$$I = (19{,}600)(249) = 4.88 \times 10^6$$

G. TANK (LH_2) AND UPPER INTERSTAGE - S-II

$$I = (19{,}600)(213) = 4.16 \times 10^6$$

CALC	Beaver	6-19-62	REVISED	DATE	Deflection of C-5 due to wind load	
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U3 4038 8000

H. ENTIRE S-IVB STAGE

$$I = \frac{(130)^2 (91.4)}{2} = 0.772 \times 10^6$$

FORCE ON SIDE OF VEHICLE (PEAK WIND SELF SUPPORTING)
(POUNDS / INCH)

DIAMETER OF SI-C & S-II = 396 INCHES

$$F = \frac{(x\ \#/ft^2)}{(144\ in^2/ft^2)} (396\ in) = 2.75\ x$$

(1) TIE DOWN POINT OF VEHICLE

$F = (2.75)(4.95) = 13.61\ \#/INCH$

(2) BOTTOM OF RP-1 TANK TIE-IN

$F = (2.75)(5.9) = 16.21\ \#/INCH$

(3) TOP TIE-IN OF RP-1 TANK

$F = (2.75)(6.9) = 19.0\ \#/INCH$

(4) BOTTOM TIE-IN OF LOX TANK

$F = (2.75)(7.7) = 21.2\ \#/INCH$

(5) TOP TIE-IN OF LOX TANK

$F = (2.75)(8.6) = 23.6\ \#/INCH$

(6) CONNECTION POINT BETWEEN SI-C & S-II

$$F = (2.75)(8.9) = 24.5 \text{ \#/INCH}$$

(7) SII; LOX – LH_2 TANK CONNECTION TO SKIN

$$F = (2.75)(9.5) = 26.1 \text{ \#/INCH}$$

(8) TOP OF S-II STAGE

$$F = (2.75)(10.25) = 28.2 \text{ \#/INCH}$$

(9) BOTTOM OF S-IVB STAGE

$$F = \frac{(10.25)(260)}{144} = 18.5 \text{ \#/INCH}$$

(10) TOP OF S-IVB STAGE

$$F = \frac{(11.2)(260)}{(144)} = 20.2 \text{ \#/INCH}$$

(11) APOLLO BOTTOM

$$F = \frac{(11.2)(154)}{144} = 12.0 \text{ \#/INCH}$$

(12) APOLLO TOP

$$F = \frac{(11.7)(154)}{144} = 12.5 \text{ \#/INCH}$$

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FORCE ON SIDE OF VEHICLE (LAUNCH WIND, STEADY STATE)

(POUNDS/INCH)

$$F = \frac{(x\ \#/ft^2)}{(144\ in^2/ft^2)}(396\ INCH) = 2.75 \cdot x\ \#/INCH$$

(1) TIEDOWN POINT OF SI-C

$F=(2.75)(2.0) = 5.50\ \#/INCH$

(2) BOTTOM OF RP-1 TANK TIE-IN

$F=(2.75)(2.5) = 6.87\ \#/INCH$

(3) TOP TIE-IN OF RP-1 TANK

$F=(2.75)(2.9) = 7.98\ \#/INCH$

(4) BOTTOM TIE-IN OF LOX TANK

$F=(2.75)(3.2) = 8.80\ \#/INCH$

(5) TOP TIE-IN OF LOX TANK

$F=(2.75)(3.7) = 10.17\ \#/INCH$

(6) CONNECTION POINT BETWEEN SI-C & S-II

$F=(2.75)(3.8) = 10.46\ \#/INCH$

(7) S-II, LOX-LH_2 TANK CONNECTION TO SKIN

$F=(2.75)(4.00) = 11.00\ \#/INCH$

(8) TOP OF S-II STAGE

$F=(2.75)(4.20) = 11.55\ \#/INCH$

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(9) BOTTOM OF S-IVB STAGE

$$F = \frac{(4.20)(260)}{144} = 7.59 \text{ \#/INCH}$$

(10) TOP OF S-IVB STAGE

$$F = \frac{(4.8)(260)}{144} = 8.67 \text{ \#/INCH}$$

(11) APOLLO BOTTOM

$$F = \frac{(4.8)(154)}{144} = 5.13 \text{ \#/INCH}$$

(12) APOLLO TOP

$$F = \frac{(5.0)(154)}{144} = 5.34 \text{ \#/INCH}$$

FORCE ON SIDE OF VEHICLE (PEAK LAUNCH WIND)
(POUNDS / INCH)

$$F = \frac{(x \text{ \#/ft}^2)}{(144 \text{ in}^2/\text{ft}^2)} (396 \text{ INCH}) = 2.75\, x \text{ \#/INCH}$$

(1) TIEDOWN POINT OF VEHICLE SI-C

$$F = (2.75)(3.0) = 8.25 \text{ \#/INCH}$$

(2) BOTTOM OF RP-1 TANK TIE-IN

$$F = (2.75)(3.6) = 9.9 \text{ \#/INCH}$$

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(3) TOP TIE-IN OF RP-1 TANK

$F = (2.75)(4.3) = 11.81$ #/INCH

(4) BOTTOM TIE-IN OF LOX TANK

$F = (2.75)(4.7) = 12.91$ #/INCH

(5) TOP TIE-IN OF LOX TANK

$F = (2.75)(5.4) = 14.84$ #/INCH

(6) CONNECTION POINT BETWEEN SI-C & S-II

$F = (2.75)(5.5) = 15.14$ #/INCH

(7) S-II, LOX-LH_2 TANK CONNECTION TO SKIN

$F = (2.75)(5.8) = 15.9$ #/INCH

(8) TOP OF S-II STAGE

$F = (2.75)(6.3) = 17.31$ #/INCH

(9) BOTTOM OF S-IV B STAGE

$F = \frac{(6.3)(260)}{144} = 11.4$ #/INCH

(10) TOP OF S-IV B STAGE

$F = \frac{(6.9)(260)}{144} = 12.48$ #/INCH

(11) APOLLO BOTTOM

$F = \frac{(6.9)(154)}{144} = 7.35$ #/INCH

(12) APOLLO TOP

$F = \frac{(7.3)(154)}{144} = 7.8$ #/INCH

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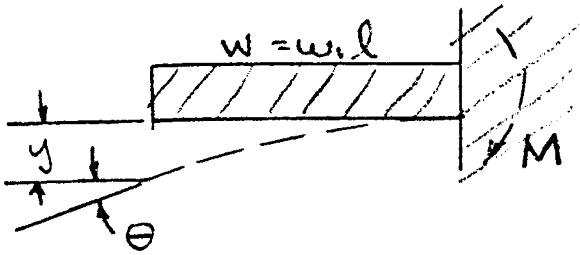
APPLICABLE EQUATIONS

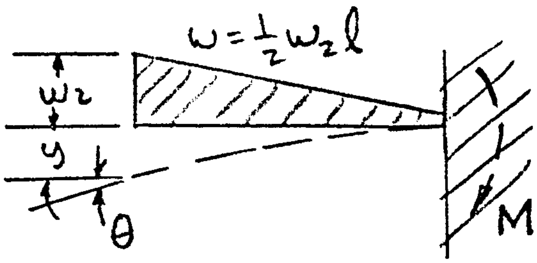
(FORMULAS FOR STRESS & STRAIN - ROARK 3RD ED)



$$y = \frac{W l^3}{8EI} = \frac{w_1 l^4}{8EI}$$

$$\theta = \frac{W l^2}{6EI} = \frac{w_1 l^3}{6EI}$$

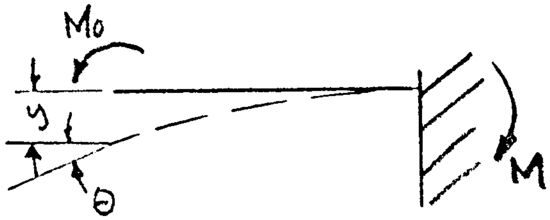
$$M = \tfrac{1}{2} W l = \frac{w_1 l^2}{2}$$



$$y = \frac{11 W l^3}{60EI} = \frac{11 w_2 l^4}{120 EI}$$

$$\theta = \frac{W l^2}{4EI} = \frac{w_2 l^3}{8EI}$$

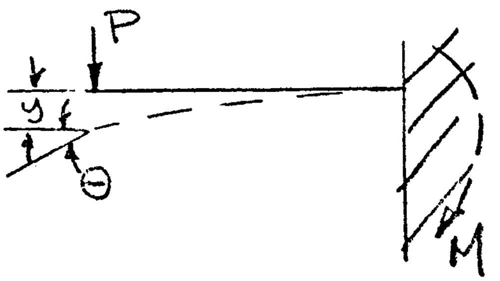
$$M = \tfrac{2}{3} W l = \frac{w_2 l^2}{3}$$



$$y = \tfrac{1}{2} \frac{M_0 l^2}{EI}$$

$$\theta = \frac{M_0 l}{EI}$$

$$M = M_0$$



$$y = \frac{P l^3}{3EI}$$

$$\theta = \frac{P l^2}{2EI}$$

$$M = P l$$

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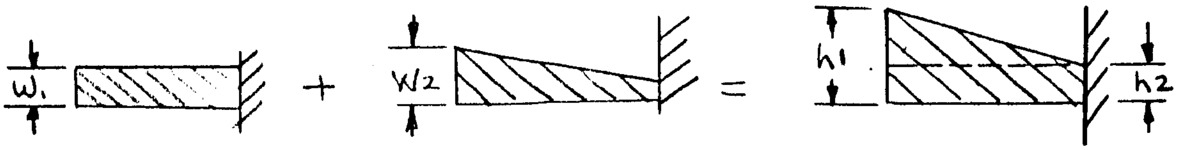
COMBINATION OF EQUATIONS



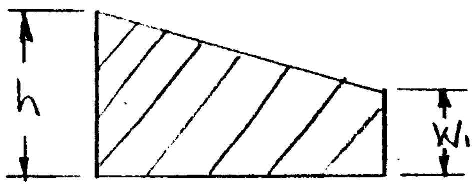
$$y = \frac{W_1 \ell^4}{8EI} + \frac{11 W_2 \ell^4}{120EI}$$

$$y = \frac{\ell^4}{8EI}\left(\frac{W_1}{1} + \frac{11}{15} W_2\right)$$

$$y = \frac{\ell^4}{8EI}\left(W_1 + \frac{11}{15}\left[h_1 - W_1\right]\right)$$

$$y = \frac{\ell^4}{8EI}\left(\frac{4W_1}{15} + \frac{11h_1}{15}\right)$$

$$y = \frac{\ell^4}{120EI}\left(4W_1 + 11h\right)$$



$$W_1 + W_2 = h_1$$
$$W_2 = h_1 - W_1$$

$$\theta = \frac{W_1 \ell^3}{6EI} + \frac{W_2 \ell^3}{8EI}$$

$$\theta = \frac{\ell^3}{EI}\left(\frac{W_1}{6} + \frac{W_2}{8}\right)$$

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$$\Theta = \frac{\ell^3}{EI}\left(\frac{w_1}{6} + \left[\frac{h_1 - w_1}{8}\right]\right)$$

$$\Theta = \frac{\ell^3}{EI}\left(\frac{w_1}{6} + \frac{h_1}{8} - \frac{w_1}{8}\right) = \frac{\ell^3}{EI}\left(\frac{w_1}{24} + \frac{3h_1}{24}\right)$$

$$\Theta = \frac{\ell^3}{24EI}\left(w_1 + 3h_1\right)$$

$$M = \frac{w_1 \ell^2}{2} + \frac{w_2 \ell^2}{3} = \ell^2\left(\frac{w_1}{2} + \frac{w_2}{3}\right)$$

$$M = \ell^2\left(\frac{w_1}{2} + \left[\frac{h_1 - w_1}{3}\right]\right) = \ell^2\left(\frac{w_1}{2} + \frac{h_1}{3} - \frac{w_1}{3}\right)$$

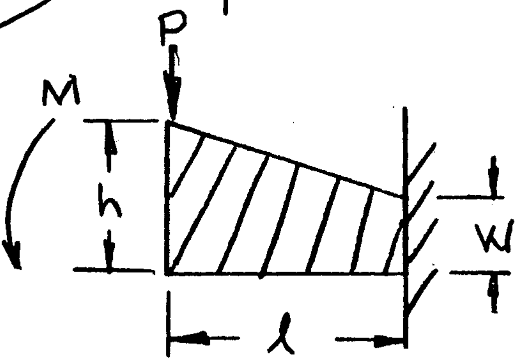
$$M = \ell^2\left(\frac{3w_1}{6} + \frac{2h_1}{6} - \frac{2w_1}{6}\right)$$

$$M = \frac{\ell^2}{6}\left(w_1 + 2h\right)$$

COMBINATION OF EQUATIONS

$$\Theta = \frac{\ell^3}{24EI}\left(w + 3h\right) + \frac{M\ell}{EI} + \frac{P\ell^2}{2EI}$$

$$\Theta = \frac{\ell}{EI}\left(\frac{\ell^3}{24}\left[w + 3h\right] + M + \frac{P\ell}{2}\right)$$



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$$y = \frac{\ell^4}{12EI}(4w+11h) + \frac{M\ell^2}{2EI} + \frac{P\ell^3}{3EI}$$

$$y = \frac{\ell^2}{EI}\left(\frac{\ell^2}{12}[4w+11h] + \frac{M}{2} + \frac{P\ell}{3}\right) \leftarrow$$

$$\Delta M = \frac{\ell^2}{6}(w+2h) + P\ell \leftarrow$$

NOTE

$\Delta M = M_2 - M_1$

REARRANGED FOR TABULAR SOLUTION

$$\theta = \frac{\ell^4}{24EI}(w+3h) + \frac{\ell}{EI}(M) + \frac{\ell^2}{2EI}(P)$$

$$y = \frac{\ell^4}{12EI}(4w+3h) + \frac{\ell^2}{2EI}(M) + \frac{\ell^3}{3EI}(P)$$

$E = 10^7$ FOR Al - MARK'S HANDBOOK

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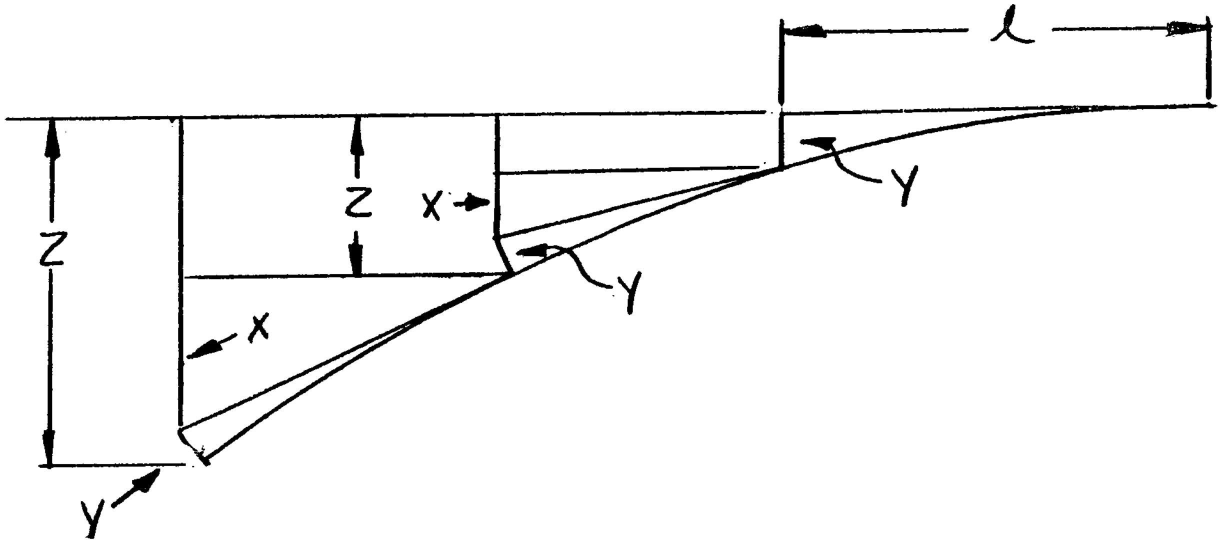
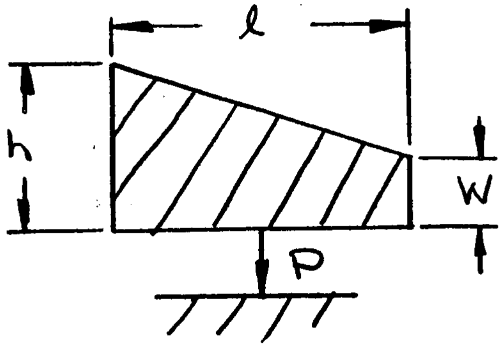
HOMENCLATURE



SHEAR LOAD — INCREMENTAL v ACCUMULATED
(STEADY STATE LAUNCH WIND)



$$P = \left(\frac{h+W}{2}\right) l$$

$$P_{11,12} = \left(\frac{5.34+5.13}{2}\right)(421) = 2,200 \text{ lbs.}$$

$$P_{9,10} = \left(\frac{8.67+7.59}{2}\right)(708) = 5,760 \text{ lbs.}$$

$$P_{7,8} = \left(\frac{11.55+11.00}{2}\right)(619) = 6,970$$

$$P_{6,7} = \left(\frac{11.00+10.46}{2}\right)(359) = 3,850$$

$$P_{5,6} = \left(\frac{10.46+10.19}{2}\right)(121) = 1,260$$

$$P_{4,5} = \left(\frac{10.19+8.80}{2}\right)(525) = 4,980$$

$$P_{3,4} = \left(\frac{8.80+7.98}{2}\right)(270) = 2,260$$

$$P_{2,3} = \left(\frac{7.98+6.89}{2}\right)(279) = 2,070$$

$$P_{1,2} = \left(\frac{5.50+6.89}{2}\right)(242) = 1,500$$

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SHEAR LOAD - (PEAK LAUNCH WIND)

$$P_{11,12} = \left(\frac{7.38 + 7.80}{2}\right)(421) = 3{,}190$$

$$P_{9,10} = \left(\frac{11.4 + 12.48}{2}\right)(708) = 8{,}450$$

$$P_{7,8} = \left(\frac{17.31 + 15.9}{2}\right)(619) = 10{,}250$$

$$P_{6,7} = \left(\frac{15.9 + 15.14}{2}\right)(359) = 5{,}560$$

$$P_{5,6} = \left(\frac{14.84 + 15.14}{2}\right)(121) = 1{,}810$$

$$P_{4,5} = \left(\frac{14.84 + 12.91}{2}\right)(525) = 7{,}290$$

$$P_{3,4} = \left(\frac{12.91 + 11.81}{2}\right)(270) = 3{,}340$$

$$P_{2,3} = \left(\frac{9.9 + 11.81}{2}\right)(279) = 3{,}150$$

$$P_{1,2} = \left(\frac{8.25 + 9.9}{2}\right)(242) = 2{,}200$$

SHEAR LOAD - (PEAK WIND-SELF SUPPORT)

$$P_{11,12} = \left(\frac{12.5 + 12.0}{2}\right)(421) = 5{,}160$$

$$P_{9,10} = \left(\frac{18.5 + 20.2}{2}\right)(708) = 13{,}700$$

$$P_{7,8} = \left(\frac{26.1 + 28.2}{2}\right)(619) = 16{,}800$$

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$$P_{6,7} = \left(\frac{26.1 + 24.5}{2}\right)(359) = 9{,}080$$

$$P_{5,6} = \left(\frac{24.5 + 23.6}{2}\right)(121) = 3{,}520$$

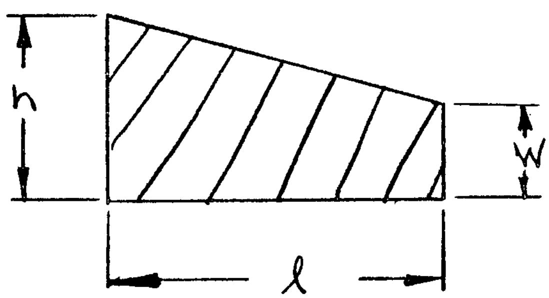
$$P_{4,5} = \left(\frac{23.6 + 21.2}{2}\right)(525) = 11{,}660$$

$$P_{3,4} = \left(\frac{21.2 + 19.0}{2}\right)(270) = 5{,}420$$

$$P_{2,3} = \left(\frac{16.21 + 19.0}{2}\right)(279) = 4{,}910$$

$$P_{1,2} = \left(\frac{13.61 + 16.21}{2}\right)(242) = 3{,}610$$

MOMENTS AT VARIOUS POINTS
(LAUNCH WIND - STEADY STATE)



$$M = \frac{\ell^2}{6}\left(W_1 + 2h\right)$$

$$M_{11} = \frac{(421)^2}{6}\left[5.13 + 2(5.34)\right] = .465 \times 10^{+6}$$

$$M_9 = \frac{(708)^2}{6}\left[7.59 + 2(8.67)\right] = 2.08 \times 10^6$$

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$$M_7 = \frac{(619)^2}{6}\left[11.00 + 2(11.55)\right] = 2.18 \times 10^6$$

$$M_6 = \frac{(359)^2}{6}\left[10.46 + 2(11.00)\right] = .698 \times 10^6$$

$$M_5 = \frac{(121)^2}{6}\left[10.19 + 2(10.46)\right] = .0759 \times 10^6$$

$$M_4 = \frac{(525)^2}{6}\left[8.80 + 2(10.19)\right] = 1.341 \times 10^6$$

$$M_3 = \frac{(270)^2}{6}\left[7.98 + 2(8.80)\right] = .312 \times 10^6$$

$$M_2 = \frac{(279)^2}{6}\left[6.89 + 2(7.98)\right] = .296 \times 10^6$$

$$M_1 = \frac{(242)^2}{6}\left[5.50 + 2(6.89)\right] = .188 \times 10^6$$

PEAK LAUNCH WIND

$$M_{11} = \frac{(421)^2}{6}\left[7.38 + 2(7.80)\right] = .680 \times 10^6$$

$$M_9 = \frac{(708)^2}{6}\left[11.4 + 2(12.48)\right] = 3.04 \times 10^6$$

$$M_7 = \frac{(619)^2}{6}\left[15.9 + 2(17.31)\right] = 3.24 \times 10^6$$

$$M_6 = \frac{(359)^2}{6}\left[15.14 + 2(15.19)\right] = .979 \times 10^6$$

$$M_5 = \frac{(121)^2}{6}\left[14.84 + 2(15.14)\right] = .110 \times 10^6$$

$$M_4 = \frac{(525)^2}{6}\left[12.91 + 2(14.84)\right] = 1.97 \times 10^6$$

$$M_3 = \frac{(270)^2}{6}\left[11.81 + 2(12.91)\right] = .457 \times 10^6$$

$$M_2 = \frac{(279)^2}{6}\left[9.9 + 2(11.81)\right] = .434 \times 10^6$$

$$M_1 = \frac{(242)^2}{6}\left[8.25 + 2(9.9)\right] = .264 \times 10^6$$

Peak Wind - Self Supporting

$$M_{11} = \frac{(421)^2}{6}\left[12.0 + 2(12.5)\right] = 1.09 \times 10^6$$

$$M_9 = \frac{(708)^2}{6}\left[18.5 + 2(20.2)\right] = 4.92 \times 10^6$$

$$M_7 = \frac{(619)^2}{6}\left[26.1 + 2(28.2)\right] = 5.26 \times 10^6$$

$$M_6 = \frac{(359)^2}{6}\left[24.5 + 2(26.1)\right] = 1.629 \times 10^6$$

$$M_5 = \frac{(121)^2}{6}\left[23.6 + 2(24.5)\right] = .177 \times 10^6$$

$$M_4 = \frac{(525)^2}{6}\left[21.2 + 2(23.6)\right] = 3.14 \times 10^6$$

$$M_3 = \frac{(270)^2}{6}\left[19.0 + 2(21.2)\right] = .745 \times 10^6$$

$$M_2 = \frac{(279)^2}{6}\left[16.21 + 2(19.0)\right] = .703 \times 10^6$$

$$M_1 = \frac{(242)^2}{6}\left[13.61 + 2(16.21)\right] = .449 \times 10^6$$

PARTS OF MOMENT DUE TO SHEAR $M = Pl$

STEADY STATE LAUNCH WIND II

$M_{11} = (0)(421) = 0$

$M_9 = (2,200)(708) = 1,560,000 = 1.56 \times 10^6$

$M_7 = (7,960)(619) = 4,930,000 = 4.93 \times 10^6$

$M_6 = (14,930)(359) = 5.35 \times 10^6$

$M_5 = (18,510)(121) = 2.24 \times 10^6$

$M_4 = (19,770)(525) = 10.39 \times 10^6$

$M_3 = (24,750)(270) = 6.69 \times 10^6$

$M_2 = (27,010)(279) = 7.54 \times 10^6$

PEAK LAUNCH WIND

$M_9 = (3190)(708) = 2.20 \times 10^6$

$M_7 = (11,615)(619) = 7.20 \times 10^6$

$M_6 = (21,865)(359) = 7.86 \times 10^6$

$M_5 = (27,425)(121) = 3.32 \times 10^6$

$M_4 = (29,235)(525) = 15.41 \times 10^6$

$M_3 = (36,525)(270) = 9.86 \times 10^6$

$M_2 = (39,865)(242) = 9.65 \times 10^6$

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PEAK WIND - SELF SUPPORTING

$$M_9 = (5{,}160)(708) = 3.65 \times 10^6$$

$$M_7 = (18{,}860)(619) = 11.71 \times 10^6$$

$$M_6 = (35{,}660)(359) = 12.81 \times 10^6$$

$$M_5 = (44{,}740)(121) = 5.410 \times 10^6$$

$$M_4 = (48{,}260)(525) = 25.3 \times 10^6$$

$$M_3 = (59{,}920)(270) = 16.15 \times 10^6$$

$$M_2 = (65{,}340)(279) = 18.2 \times 10^6$$

SOLUTION OF CONSTANTS:

SECTION 1 TO 2 → $_1S_2$

$_1S_2$ $\quad \ell = 242$

$\ell^2 = 58{,}600$

$\ell^3 = 141{,}900{,}000 = 14.1 \times 10^6$

$\ell^4 = 3{,}440{,}000{,}000 = 3{,}440 \times 10^6$

$I = 14.0 \times 10^6$

$$\frac{\ell^4}{24EI} = \frac{3{,}440 \times \cancel{10^6}}{(24)(10^7)(14 \times \cancel{10^6})} = 1.025 \times 10^{-6}$$

$$\frac{\ell^4}{12EI} = 2.050 \times 10^{-6}$$

$$\frac{\ell}{EI} = \frac{242}{(10^7)(14.0 \times 10^6)} = 1.73 \times 10^{-12}$$

$$\frac{\ell^2}{2EI} = \frac{(58{,}600)}{2(10^7)(14.0 \times 10^6)} = 209.5 \times 10^{-12}$$

$$\frac{\ell^3}{3EI} = \frac{(14.19 \times \cancel{10^6})}{3(10^7)(14.0 \times \cancel{10^6})} = .0337 \times 10^{-6}$$

$_2S_3$ $\quad \ell = 279$

$\ell^2 = 77{,}800$

$\ell^3 = 21{,}700{,}000$

$\ell^4 = 6{,}025 \times 10^6$

$I = 6.45 \times 10^6$

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$$\frac{\ell^4}{24EI} = \frac{6{,}025 \times \cancel{10^6}}{24(10)(10^6)(6.45)(\cancel{10^6})} = 3.89 \times 10^{-6}$$

$$\frac{\ell}{EI} = \frac{279}{(10)(10^6)(6.45)(10^6)} = 4.32 \times 10^{-12}$$

$$\frac{\ell^2}{2EI} = \frac{77{,}800}{2(10)(10^6)(6.45 \times 10^6)} = 604 \times 10^{-12}$$

$$\frac{\ell^3}{3EI} = \frac{21.7 \times 10^6}{3(10)(10^6)(6.45 \times 10^6)} = .1122 \times 10^{-6}$$

${}_3S_4$

$\ell = 270$

$\ell^2 = 72{,}900$

$\ell^3 = 19.7 \times 10^6$

$\ell^4 = 5{,}310 \times 10^6$

$I = 5.29 \times 10^{+6}$

$$\frac{\ell^4}{24EI} = \frac{5{,}310 \times \cancel{10^6}}{(24)(10)(10^6)(4.68)(\cancel{10^6})} = 4.71 \times 10^{-6}$$

$$\frac{\ell}{EI} = \frac{(270)}{(10)(10^6)(4.68 \times 10^6)} = 5.79 \times 10^{-12}$$

$$\frac{\ell^2}{2EI} = \frac{(72{,}900)}{2(10)(10^6)(4.68 \times 10^6)} = 779. \times 10^{-12}$$

$$\frac{\ell^3}{3EI} = \frac{19.7 \times 10^{+6}}{3(10)(10^6)(4.68 \times 10^6)} = .1400 \times 10^{-6}$$

${}_4S_5$

$$\ell = 525$$
$$\ell^2 = 278{,}000$$
$$\ell^3 = 144.9 \times 10^6$$
$$\ell^4 = 77{,}400 \times 10^6$$
$$I = 6.45 \times 10^6$$

$$\frac{\ell^4}{24EI} = \frac{77{,}400 \times \cancel{10^6}}{(24)(10)(10^6)(6.45)(\cancel{10^6})} = 50.0 \times 10^{-6}$$

$$\frac{\ell}{EI} = \frac{525}{(10)(10^6)(6.45 \times 10^6)} = 8.14 \times 10^{-12}$$

$$\frac{\ell^2}{2EI} = \frac{(278{,}000)}{2(10)(10^6)(6.45 \times 10^6)} = 2{,}160 \times 10^{-12}$$

$$\frac{\ell^3}{3EI} = \frac{(144.9 \times 10^6)}{(3)(10)(10^6)(6.45 \times 10^6)} = .746 \times 10^{-6}$$

${}_5S_6$

$$\ell = 121$$
$$\ell^2 = 1{,}465$$
$$\ell^3 = 177{,}000$$
$$\ell^4 = 2.15 \times 10^6$$
$$I = 5.07 \times 10^6$$

$$\frac{\ell^4}{24EI} = \frac{215 \times \cancel{10^6}}{24(10)(10^6)(5.07 \times \cancel{10^6})} = .00177 \times 10^{-6}$$

$$\frac{\ell}{EI} = \frac{121}{(10)(10^6)(5.07)(10^6)} = 2.39 \times 10^{-12}$$

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$$\frac{l^2}{2EI} = \frac{(1{,}465)}{2(10)(10^6)(5.07 \times 10^6)} = 14.45 \times 10^{-12}$$

$$\frac{l^3}{3EI} = \frac{(177{,}000)}{3(10)(10^6)(5.07 \times 10^6)} = .001164 \times 10^{-6}$$

${}_4S_7$

$l = 359$

$l^2 = 129{,}000$

$l^3 = 46.3 \times 10^6$

$l^4 = 16{,}650 \times 10^6$

$I = 4.88 \times 10^{+6}$

$$\frac{l^4}{24EI} = \frac{16{,}650 \times \cancel{10^6}}{24(10)(10^6)(4.88)\cancel{(10^6)}} = 14.21 \times 10^{-6}$$

$$\frac{l}{EI} = \frac{359}{10(10^6)(4.88 \times 10^6)} = 7.35 \times 10^{-12}$$

$$\frac{l^2}{2EI} = \frac{(129{,}000)}{2(10)(10^6)(4.88)(10^6)} = 1{,}320 \times 10^{-12}$$

$$\frac{l^3}{3EI} = \frac{46.3 \times 10^6}{3(10)(10^6)(4.88)(10^6)} = .316 \times 10^{-6}$$

$_7S_8$ $\quad \ell = 619$

$\ell^2 = 382{,}000$

$\ell^3 = 237 \times 10^6$

$\ell^4 = 146{,}000 \times 10^6$

$I = 4.16 \times 10^6$

$$\frac{\ell^4}{24EI} = \frac{146{,}000 \times \cancel{10^6}}{(24)(10)(10^6)(4.16 \times 10^6)} = 146 \times 10^6$$

$$\frac{\ell}{EI} = \frac{(619)}{(10)(10^6)(4.16 \times 10^6)} = 14.86 \times 10^{-12}$$

$$\frac{\ell^2}{2EI} = \frac{(382{,}000)}{(2)(10)(10^6)(4.16 \times 10^6)} = 4{,}590 \times 10^{-12}$$

$$\frac{\ell^3}{3EI} = \frac{(237 \times 10^6)}{3(10)(10^6)(4.16 \times 10^6)} = 1.896 \times 10^{-6}$$

$_9S_{10}$ $\quad \ell = 708$

$\ell^2 = 501{,}000$

$\ell^3 = 355 \times 10^6$

$\ell^4 = 252{,}000 \times 10^6$

$I = .772 \times 10^6$

$$\frac{\ell^4}{24EI} = \frac{(252{,}000)\cancel{10^6}}{24(10)(\cancel{10^6})(.772 \times 10^6)} = 1{,}360 \times 10^{-6}$$

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$$\frac{\ell}{EI} = \frac{708}{10(10^6)(.772 \times 10^6)} = 91.6 \times 10^{-12}$$

$$\frac{\ell^2}{2EI} = \frac{501{,}00\cancel{0}}{2(1\cancel{0})(10^6)(.772 \times 10^6)} = 32{,}400 \times 10^{-12}$$

$$\frac{\ell^3}{3EI} = \frac{355 \times 10^6}{3(10)(10^6)(.772 \times 10^6)} = 15.33 \times 10^{-6}$$

$$\Theta = \frac{\ell^4}{24EI}(W+3h) + \frac{\ell}{EI}(M) + \frac{\ell^2}{2EI}(P)$$

STEADY STATE LAUNCH WIND II

$$\Theta_2 = \frac{(1.025)}{10^6}(26.17) + \frac{1.73}{10^{12}}(46.18 \cdot 10^6) + \frac{209.5}{10^{12}}(29{,}080)$$

$$\Theta_2 = \frac{26.8}{10^6} + \frac{80.0}{10^6} + \frac{6.09}{10^6} = \frac{112.90}{10^6} = \Theta_2$$

$$\Theta_3 = \frac{(3.89)}{10^6}(30.81) + \frac{4.35}{10^{12}{}_6}(38.31)^{(10^6)} + \frac{604.}{10^{16}}(27{,}010)$$

$$\Theta_3 = \frac{120}{10^6} + \frac{166.6}{10^6} + \frac{16.31}{10^6} = 302.9 \times 10^{-6}$$

$$\Theta_4 = \frac{4.71}{10^6}(34.38) + \frac{5.79}{10^{12}}\frac{(31.31)}{10^{-6}} + \frac{779}{10^{12}}(24{,}750)$$

$$\Theta_4 = \frac{162}{10^6} + \frac{181.0}{10^6} + \frac{19.28}{10^6} = 362.3 \times 10^{-6}$$

$$\Theta_5 = \frac{50.0}{10^6}(39.37) + \frac{8.14}{10^{12}}(19.58 \times 10^6) + \frac{2{,}160}{10^{12}}(19{,}770)$$

$$\Theta_5 = \frac{1{,}969}{10^6} + \frac{159.7}{10^6} + \frac{42.7}{10^6} = \frac{2171.4}{10^6}$$

$$\Theta_6 = \frac{.00177}{10^6}(41.57) + \frac{2.39}{10^{12}}(17.26 \times 10^6) + \frac{14.45}{10^{12}}(18{,}510)$$

$$\Theta_6 = \frac{.0736}{10^6} + \frac{41.3}{10^6} + \frac{2.68}{10^6} = \frac{44.05}{10^6}$$

$$\Theta_7 = \frac{14.21}{10^6}(43.46) + \frac{7.35}{10^{12}}(11.22 \times 10^6) + \frac{1{,}320}{10^{12}}(14{,}930)$$

$$\Theta_7 = \frac{619}{10^6} + \frac{82.5}{10^6} + \frac{19.7}{10^6} + \frac{19.7}{10^6} = \frac{721.2}{10^6}$$

$$\Theta_8 = \frac{146.0}{10^6}(45.65) + \frac{14.86}{10^{12}}(4.105 \times 10^6) + \frac{4{,}590}{10^{12}}(7{,}960)$$

$$\Theta_8 = \frac{6{,}660}{10^6} + \frac{61.0}{10^6} + \frac{36.5}{10^6} = \frac{6{,}757.5}{10^6}$$

$$\Theta_{10} = \frac{1{,}360}{10^6}(33.6) + \frac{91.6}{10^{12}}(.465 \times 10^6) + \frac{32{,}400}{10^{12}}(2{,}200)$$

$$\Theta_{10} = \frac{45{,}700}{10^6} + \frac{42.6}{10^6} + \frac{71.4}{10^6} = \frac{45{,}810}{10^6}$$

$$\Theta = \frac{\ell^4}{24EI}(W+3h) + \frac{\ell}{EI}(M) + \frac{\ell^2}{2EI}(P)$$

PEAK LAUNCH WIND

$$\Theta_2 = \frac{1.025}{10^6}(37.95) + \frac{1.73}{10^{12}}(66.41 \times 10^6) + \frac{209.5}{10^{12}}(43{,}015)$$

$$\Theta_2 = \frac{38.9}{10^6} + \frac{114.9}{10^6} + \frac{9.01}{10^6} = \frac{162.8}{10^6}$$

$$\Theta_3 = \frac{3.89}{10^6}(45.33) + \frac{4.32}{10^{12}}(56.33 \times 10^6) + \frac{604.0}{10^{12}}(39{,}865)$$

$$\Theta_3 = \frac{176.2}{10^6} + \frac{243.0}{10^6} + \frac{24.1}{10^6} = \frac{443.3}{10^6}$$

$$\Theta_4 = \frac{4.71}{10^6}(50.54) + \frac{5.79}{10^{12}}(46.01 \times 10^6) + \frac{779}{10^{12}}(36{,}525)$$

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$$\Theta_4 = \frac{238}{10^6} + \frac{267.0}{10^6} + \frac{27.6}{10^6} = \frac{532.6}{10^6}$$

$$\Theta_5 = \frac{50.0}{10^6}(57.43) + \frac{8.14}{10^{12}}(28.6 \times 10^6) + \frac{2{,}160}{10^{12}}(29{,}235)$$

$$\Theta_5 = \frac{2870}{10^6} + \frac{232}{10^6} + \frac{63.1}{10^6} = \frac{3165}{10^6}$$

$$\Theta_6 = \frac{.00177}{10^6}(60.26) + \frac{2.39}{10^{12}}(25.2 \times 10^6) + \frac{14.45}{10^{12}}(27{,}425)$$

$$\Theta_6 = \frac{.1069}{10^6} + \frac{60.4}{10^6} + \frac{.394}{10^6} = \frac{60.9}{10^6}$$

$$\Theta_7 = \frac{14.21}{10^{+6}}(62.84) + \frac{7.35}{10^{12}}(16.36 \times 10^6) + \frac{1320}{10^{12}}(21{,}865$$

$$\Theta_7 = \frac{894}{10^6} + \frac{120.5}{10^6} + \frac{28.9}{10^6} = \frac{1043}{10^6}$$

$$\Theta_8 = \frac{146}{10^6}(67.83) + \frac{14.86}{10^{12}}(5.92 \times 10^6) + \frac{4{,}590}{10^{-12}}(11{,}615)$$

$$\Theta_8 = \frac{9{,}900}{10^6} + \frac{87.9}{10^6} + \frac{53.4}{10^6} = \frac{10{,}041}{10^6}$$

$$\Theta_{10} = \frac{1360}{10^6}(48.84) + \frac{91.6}{10^{12}}(.683 \times 10^6) + \frac{32{,}400}{10^{12}}(3{,}190)$$

$$\Theta_{10} = \frac{66{,}500}{10^6} + \frac{62.4}{10^6} + \frac{103.4}{10^6} = \frac{66{,}666}{10^6}$$

$$\Theta = \frac{l^4}{24EI}(W + 3h) + \frac{l}{EI}(M) + \frac{l^2}{2EI}(P)$$

PEAK WIND - SELF SUPPORTING

$$\Theta_2 = \frac{1.025}{10^6}(62.24) + \frac{1.73}{10^{12}}(111.9 \times 10^6) + \frac{209.5}{10^{12}}(70{,}250)$$

$$\theta_2 = \frac{63.9}{10^6} + \frac{193.0}{10^6} + \frac{14.71}{10^6} = \frac{271.6}{10^6}$$

$$\theta_3 = \frac{3.89}{10^6}(73.21) + \frac{4.32}{10^{12}}(193.00 \times 10^6) + \frac{604}{10^{12}}(65,340)$$

$$\theta_3 = \frac{284}{10^6} + \frac{402.0}{10^6} + \frac{39.4}{10^6} = \frac{725.4}{10^6}$$

$$\theta_4 = \frac{4.71}{10^6}(82.6) + \frac{5.79}{10^{12}}(76.1 \times 10^6) \frac{779}{10^{12}}(59,920)$$

$$\theta_4 = \frac{389}{10^6} + \frac{441}{10^6} + \frac{46.5}{10^6} = \frac{876.5}{10^6}$$

$$\theta_5 = \frac{50.0}{10^6}(92.0) + \frac{8.14}{10^{+12}}(47.66 \times 10^6) + \frac{2,160}{10^{12}}(48,260)$$

$$\theta_5 = \frac{4,600}{10^6} + \frac{386}{10^6} + \frac{104.2}{10^6} = \frac{5,090}{10^6}$$

$$\theta_6 = \frac{.00177}{10^6}(97.1) + \frac{2.39}{10^{12}}(42.07 \times 10^6) + \frac{14.45}{10^{12}}(44,740)$$

$$\theta_6 = \frac{.172}{10^6} + \frac{100.2}{10^6} + \frac{.646}{10^6} = \frac{101.2}{10^6}$$

$$\theta_7 = \frac{14.21}{10^6}(102.8) + \frac{7.35}{10^{12}}(27.63 \times 10^6) + \frac{1320}{10^6}(35,660)$$

$$\theta_7 = \frac{1,460}{10^6} + \frac{203.0}{10^6} + \frac{47.1}{10^6} = \frac{1710}{10^6}$$

$$\theta_8 = \frac{146.0}{10^6}(110.7) + \frac{14.86}{10^{12}}(9.66)10^6 + \frac{4,590}{10^{12}}(18,860)$$

$$\theta_8 = \frac{16,150}{10^6} + \frac{148}{10^6} + \frac{86.6}{10^6} = \frac{16,384}{10^6}$$

$$\theta_{10} = \frac{1,360}{10^6}(79.1) + \frac{91.6}{10^{12}}(1.09 \times 10^6) + \frac{32,400}{10^{12}}(5,160)$$

$$\theta_{10} = \frac{107,700}{10^6} + \frac{100}{10^6} + \frac{167.3}{10^6} = \frac{107,970}{10^6}$$

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SOLUTION OF X

STEADY STATE LAUNCH WIND II

$X_3 = (279)(112.9)(10^{-6}) = .314$

$X_4 = (270)(415.8)(10^{-6}) = 1.124$

$X_5 = (525)(778.0)(10^{-6}) = .409$

$X_6 = (121)(2{,}949)(10^{-6}) = .357$

$X_7 = (359)(2{,}993)(10^{-6}) = 1.07$

$X_8 = (619)(3{,}714)(10^{-6}) = 2.30$

$X_{10} = (708)(10{,}472)(10^{-6}) = 7.41$

PEAK LAUNCH WIND III

$X_3 = (279)(162.8)(10^{-6}) = .455$

$X_4 = (270)(606.1)(10^{-6}) = 1.639$

$X_5 = (525)(1{,}138.7)(10^{-6}) = .596$

$X_6 = (121)(4{,}303)(10^{-6}) = .522$

$X_7 = (359)(4{,}365)(10^{-6}) = 1.569$

$X_8 = (619)(5{,}408)(10^{-6}) = 3.34$

$X_{10} = (708)(15{,}500)(10^{-6}) = 10.99$

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PEAK WIND SELF-SUPPORTING

$$X_3 = (279)(271.6)(10^{-6}) = .759$$

$$X_4 = (270)(997.0)(10^{-6}) = 2.69$$

$$X_5 = (525)(1,874)(10^{-6}) = .984$$

$$X_6 = (121)(6,964)(10^{-6}) = .842$$

$$X_7 = (359)(7065)(10^{-6}) = 2.54$$

$$X_8 = (619)(8775)(10^{-6}) = 5.40$$

$$X_{10} = (708)(25,159)(10^{-6}) = 17.81$$

SOLUTION OF Y

$$Y = \frac{\ell^4}{12EI}(4W+3h) + \frac{\ell^2}{2EI}(M) + \frac{\ell^3}{3EI}(P)$$

LAUNCH WIND STEADY STATE II

$$y_2 = \frac{2.05}{10^6}(42.67) + \frac{209.5}{10^{12}}(46.15 \times 10^6) + \frac{.0377}{10^6}(29{,}080)$$

$$y_2 = \frac{87.4}{10^6} + \frac{9{,}640}{10^6} + \frac{1{,}100}{10^6} = \frac{10{,}827}{10^6} = .01083$$

$$y_3 = \frac{7.78}{10^6}(51.48) + \frac{604}{10^{12}}(38.3 \times 10^6) + \frac{.1122}{10^6}(27{,}010)$$

$$y_3 = \frac{400}{10^6} + \frac{23{,}100}{10^6} + \frac{3{,}030}{10^6} = \frac{26{,}530}{10^6} = .02653$$

$$y_4 = \frac{9.42}{10^6}(58.32) + \frac{779}{10^{12}}(31.31 \times 10^6) + \frac{.1400}{10^6}(24{,}750)$$

$$y_4 = \frac{549}{10^6} + \frac{24{,}400}{10^6} + \frac{3{,}490}{10^6} = \frac{28{,}439}{10^6} = .028439$$

$$y_5 = \frac{100}{10^6}(65.77) + \frac{2160}{10^{12}}(19.58 \times 10^6) + \frac{.746}{10^6}(19{,}770)$$

$$y_5 = \frac{6{,}577}{10^6} + \frac{42{,}300}{10^6} + \frac{14{,}750}{10^6} = \frac{63{,}627}{10^6} = .06363$$

$$y_6 = \frac{.00354}{10^6}(72.14) + \frac{14.45}{10^{12}}(17.26 \times 10^6) + \frac{.001164}{10^6}(18{,}510)$$

$$y_6 = \frac{.255}{10^6} + \frac{249}{10^6} + \frac{21.6}{10^6} = \frac{270.9}{10^6} = .000271$$

$$y_7 = \frac{28.42}{10^6}(74.84) + \frac{1{,}320}{10^{12}}(11.21 \times 10^6) + \frac{.316}{10^6}(14{,}930)$$

$$y_7 = \frac{2050}{10^6} + \frac{14{,}810}{10^6} + \frac{4{,}720}{10^6} = \frac{21{,}580}{10^6} = .021580$$

$$y_8 = \frac{292.0}{10^6}(78.7) + \frac{4,590}{10^{12}}(4.105 \times 10^6) + \frac{1.896}{10^6}(7,960)$$

$$y_8 = \frac{23,000}{10^6} + \frac{18,850}{10^6} + \frac{15,100}{10^6} = \frac{56,950}{10^6} = .05695$$

$$y_{10} = \frac{2,720}{10^6}(56.37) + \frac{32,400}{10^{12}}(.465)10^6 + \frac{15.33}{10^6}(2,200)$$

$$y_{10} = \frac{153,100}{10^6} + \frac{15,050}{10^6} + \frac{33,700}{10^6} = \frac{201,750}{10^6} = .20175$$

$$y = \frac{\ell^4}{12EI}(4W+3h) + \frac{\ell^2}{2EI}(M) + \frac{\ell^3}{3EI}(P)$$

PEAK LAUNCH WIND III

$$y_2 = \frac{2.05}{10^6}(62.7) + \frac{209.5}{10^{12}}(66.41 \times 10^6) + \frac{.0337}{10^6}(43,015)$$

$$y_2 = \frac{129.0}{10^6} + \frac{13,860}{10^6} + \frac{1,450}{10^6} = \frac{15,439}{10^6} = .01544$$

$$y_3 = \frac{7.78}{10^6}(75.03) + \frac{604}{10^{12}}(56.33 \times 10^6) + \frac{.1122}{10^6}(39,865)$$

$$y_3 = \frac{585}{10^6} + \frac{33,900}{10^6} + \frac{4,490}{10^6} = \frac{38,975}{10^6} = .038975$$

$$y_4 = \frac{9.42}{10^6}(85.97) + \frac{779.0}{10^{12}}(46.009 \times 10^6) + \frac{.1400}{10^6}(36,525)$$

$$y_4 = \frac{824}{10^6} + \frac{35,800}{10^6} + \frac{4960}{10^6} = \frac{41,580}{10^6} = .04158$$

$$y_5 = \frac{100}{10^6}(96.16) + \frac{2,160}{10^{12}}(28.6 \times 10^6) + \frac{.746}{10^6}(29,235)$$

$$y_5 = \frac{9616}{10^6} + \frac{61,900}{10^6} + \frac{21,800}{10^6} = \frac{93,316}{10^6} = .09332$$

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$$y_6 = \frac{.00354}{10^6}(104.78) + \frac{14.45}{10^{12}}(25.2 \times 10^6) + \frac{.001164}{10^6}(27{,}425)$$

$$y_6 = \frac{.371}{10^6} + \frac{364.0}{10^6} + \frac{31.9}{10^6} = \frac{396.3}{10^6} = .000396$$

$$y_7 = \frac{28.42}{10^6}(108.26) + \frac{1{,}320}{10^{12}}(16.36 \times 10^6) + \frac{.316}{10^6}(21{,}865)$$

$$y_7 = \frac{3080}{10^6} + \frac{21{,}600}{10^6} + \frac{6{,}910}{10^6} = \frac{31{,}590}{10^6} = .03159$$

$$y_8 = \frac{292}{10^6}(115.5) + \frac{4{,}590}{10^{12}}(5.92 \times 10^6) + \frac{1.896}{10^6}(11{,}615)$$

$$y_8 = \frac{33{,}700}{10^6} + \frac{27{,}150}{10^6} + \frac{21{,}900}{10^6} = \frac{82{,}750}{10^6} = .08275$$

$$y_{10} = \frac{2{,}720}{10^6}(83.04) + \frac{32{,}400}{10^{12}}(.680 \times 10^6) + \frac{15.33}{10^6}(3{,}190)$$

$$y_{10} = \frac{218{,}000}{10^6} + \frac{22{,}000}{10^6} + \frac{49{,}000}{10^6} = \frac{289{,}000}{10^6} = .289$$

$$y = \frac{\ell^4}{12EI}(4W + 3h) + \frac{\ell^2}{2EI}(M) + \frac{\ell^3}{3EI}(P)$$

PEAK WIND - SELF SUPPORTING I

$$y_2 = \frac{2.05}{10^6}(103.07) + \frac{209.5}{10^{12}}(111.9)10^6 + \frac{.0337}{10^6}(70{,}250)$$

$$y_2 = \frac{211.5}{10^6} + \frac{18{,}750}{10^6} + \frac{2{,}370}{10^6} = \frac{21{,}332}{10^6} = .02133$$

$$y_3 = \frac{7.78}{10^6}(124.84) + \frac{604.0}{10^{12}}(93.00)10^6 + \frac{.1122}{10^6}(65{,}340)$$

$$y_3 = \frac{970}{10^6} + \frac{56{,}100}{10^6} + \frac{7340}{10^6} = \frac{64{,}410}{10^6} = .06441$$

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$$y_4 = \frac{9.42}{10^6}(139.6) + \frac{779}{10^{12}}(76.1 \times 10^6) + \frac{.1400}{10^6}(59{,}920)$$

$$y_4 = \frac{1{,}315.0}{10^6} + \frac{59{,}400}{10^6} + \frac{8{,}360}{10^6} = \frac{69{,}075}{10^6} = .06908$$

$$y_5 = \frac{100}{10^6}(155.2) + \frac{2{,}160}{10^{12}}(47.66 \times 10^6) + \frac{.746}{10^6}(48{,}260)$$

$$y_5 = \frac{15{,}500}{10^6} + \frac{103{,}000}{10^6} + \frac{36{,}200}{10^6} = \frac{154{,}700}{10^6} = .1547$$

$$y_6 = \frac{.00354}{10^6}(167.9) + \frac{14.45}{10^{12}}(42.07 \times 10^6) + \frac{.001164}{10^6}(44{,}740)$$

$$y_6 = \frac{.594}{10^6} + \frac{606}{10^6} + \frac{52.1}{10^6} = \frac{658.7}{10^6} = .000659$$

$$y_7 = \frac{28.42}{10^6}(176.3) + \frac{1{,}320}{10^{12}}(27.63 \times 10^6) + \frac{.316}{10^6}(35{,}660)$$

$$y_7 = \frac{5010}{10^6} + \frac{36{,}500}{10^6} + \frac{11{,}300}{10^6} = \frac{52{,}810}{10^6} = .05281$$

$$y_8 = \frac{292}{10^6}(189) + \frac{4{,}590}{10^{12}}(9.66 \times 10^6) + \frac{1{,}896}{10^6}(18{,}860)$$

$$y_8 = \frac{55{,}300}{10^6} + \frac{44{,}400.0}{10^6} + \frac{35{,}800}{10^6} = \frac{135{,}500}{10^6} = .1355$$

$$y_{10} = \frac{2{,}720}{10^6}(134.6) + \frac{32{,}400}{10^{12}}(1.09)10^6 + \frac{15.33}{10^6}(5{,}160)$$

$$y_{10} = \frac{366{,}000}{10^6} + \frac{35{,}400}{10^6} + \frac{79{,}400}{10^6} = \frac{480{,}800}{10^6} = .4808$$

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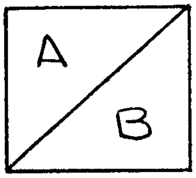
EXPLANATION OF NUMBERS IN COLUMNS

CASES

I. PEAK WIND - SELF SUPPORTING

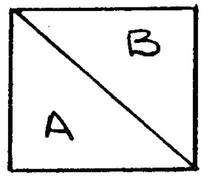
II. STEADY STATE LAUNCH WIND

III PEAK LAUNCH WIND



A = DENOTES INCREMANTAL VALUES

B = DENOTES RUNNING SUMS



MOMENTS SUMMED FROM TOP DOWN

ANGLES, AND DEFLECTIONS ARE SUMMED FROM THE BOTTOM UP

FOR THE θ AND Y EQUATIONS; M IS THE RUNNINGS SUM IN THE BLOCK ABOVE THE SECTION UNDER STUDY:

EXAMPLE: FOR θ_{III} BETWEEN SECTIONS 5 + 4

$$\theta = \frac{\ell^4}{12EI}(W+3h) + \frac{\ell}{EI}(M) + \frac{\ell^2}{2EI}(P)$$

$$\theta = \frac{50}{10^6}(57.43) + \left(\frac{8.14}{10^{12}}\right)(28.6 \times 10^6) + \frac{2{,}160}{10^6}(29{,}235)$$

NOTE: ALSO THAT P IS THE RUNNING SUM FROM THE SECTION ABOVE.

A-104

BY Bezuur DATE ______ SUBJECT ______ SHEET NO. ___ OF ___
CHKD. BY ______ DATE ______ JOB NO. ______

C.E. Bezuur 6-19-62
Total Deflection

ω × 3↔ — θ × 10[6]

Station	II	III	I	θ_{II}	θ_{III}	θ_{I}	X_{II}	X_{III}	X_{I}	Y_{II}	Y_{III}	Y_{I}	Z_{II}	Z_{III}	Z_{I}
11/10 – 9/8	33.60	48.84	79.1	56,280 / 45,810	82,115 / 66,666	133,129 / 107,970	12.98 / 7.41	19.111 / 10.99	31.025 / 17.81	.40998 / .20175	.59306 / .289	.9623 / .4808	13.39	19.70	32.00
9/8 – 7	45.65	67.83	110.7	10,472 / 6,757.5	15,449 / 10,041	25,159 / 16,384	5.571 / 2.30	8.721 / 3.34	13.215 / 5.40	.20823 / .05695	.30406 / .08275	.4815 / .135	5.78	8.43	13.70
7 – 6	43.46	62.84	102.8	3,714 / 221.2	15,408 / 1043	8,775 / 1710	3.27 / 1.07	4.781 / 1.569	7.815 / 2.54	.15128 / .02158	.2213 / .03159	.3460 / .02581	3.42	5.00	8.16
6 – 5	41.57	60.26	97.1	2993 / 44.05	4355 / 60.9	7,065 / 101.2	2.204 / .357	3.212 / .522	5.275 / .842	.1297 / .000271	.1897 / .000394	.3202 / .000659	2.33	3.40	5.60
5 – 4	39.37	57.43	92.0	2949 / 2171.4	4,303 / 3165	6,964 / 5,090	-1.842 / 1.409	2.690 / .596	4.433 / .984	.1294 / .06563	.1893 / .09332	.3195 / .1547	1.98	2.88	4.75
4 – 3	34.38	50.54	82.6	778.1 / 362.3	1,138.7 / 532.6	1,879 / 876.5	1.438 / 1.124	2.094 / 1.639	3.449 / 2.69	.06580 / .02849	.0960 / .04158	.16482 / .06908	1.504	2.19	3.61
3 – 2	30.81	45.33	73.21	415.8 / 302.9	606.1 / 443.3	997.0 / 725.4	.314 / .314	.455 / .455	.759 / .759	.03736 / .02653	.0544 / .038975	.08574 / .06441	.351	.509	.845
2 – 1	26.17	37.95	62.24	112.9 / 112.9	162.8 / 162.8	271.6 / 271.6	~~ ~~	~~ ~~	~~ ~~	.01083 / .01083	.01544 / .01544	.02133 / .02133	.0108	.0154	.0108

BY Beaver DATE ______ SUBJECT ______ SHEET NO. ______ OF ______
CHKD. BY ______ DATE ______ JOB NO. ______

CE Beaver 6-17-62

$4W + 34$

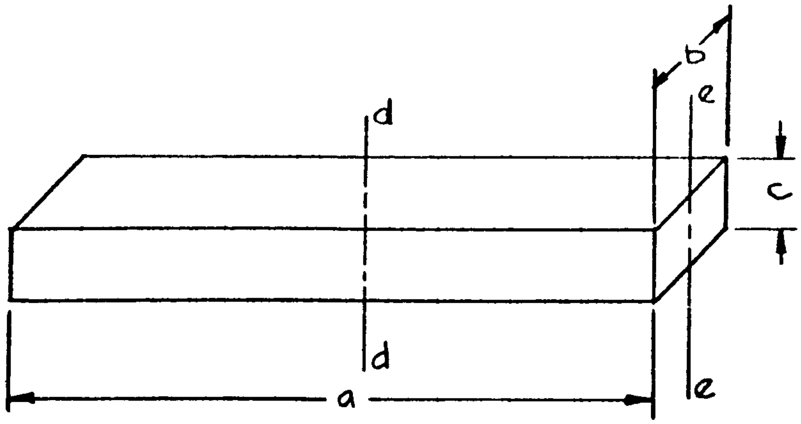
$\underbrace{\quad\quad}_{M \times 10^{-6}}$

Sta.	P_{II}	P_{III}	P_{I}	M_{II}	M_{III}	M_{I}	$\frac{l^4}{24EI}$	$\frac{l}{EI}$	$\frac{l^2}{2EI}$	$\frac{l^4}{12EI}$	$\frac{l^3}{3EI}$	II	III	I
12	2,200 / 2200	3,190 / 3190	5,160 / 5160	.465 / .465	.680 / .680	1.09 / 1.09	≶	≶	≶	≶	≶	≶	≶	≶
11/10	5760 / 7,960	8425 / 11,615	13700 / 18,860	3.64 / 4.105	5.24 / 5.920	8.57 / 9.64	$1,360 \times 10^{-6}$	91.6×10^{-12}	$32,400 \times 10^{-12}$	$2,720 \times 10^{-6}$	15.33×10^{-6}	56.37	83.04	134.6
9/8	6,970 / 14930	10,250 / 21,865	16,800 / 35,660	7.11 / [illegible]	10.44 / 16.36	16.97 / 27.63	146.0×10^{-6}	14.86×10^{-12}	$4,590 \times 10^{-12}$	292×10^{-6}	1.896×10^{-6}	78.65	115.53	189.0
7	3,580 / 18,510	5,560 / 27425	9,080 / 44,740	6.048 / 17.261	8.839 / 25.199	14.439 / 42.07	14.21×10^{-6}	7.35×10^{-12}	$1,320 \times 10^{-12}$	28.42×10^{-6}	$.316 \times 10^{-6}$	74.74	108.26	176.3
6	1260 / 19770	1810 / 29235	3520 / 48260	2.316 / 19.579	3.430 / 28.629	5.587 / 47.66	$.00177 \times 10^{-6}$	2.39×10^{-12}	14.45×10^{-12}	$.00354 \times 10^{-6}$	$.001164 \times 10^{-6}$	72.14	104.78	167.9
5	4980 / 24,750	7290 / 36,525	11,660 / 59,920	11.731 / 31.31	17.38 / 46.009	28.44 / 76.10	50.0×10^{-6}	8.14×10^{-12}	$2,160 \times 10^{-6}$	100.0×10^{-6}	$.746 \times 10^{-6}$	65.77	96.16	155.2
4	2260 / 27010	3340 / 39865	5420 / 65340	7.002 / 38.312	10.317 / 56.33	16.895 / 93.00	4.71×10^{-6}	5.79×10^{-12}	779.0×10^{-12}	9.42×10^{-6}	$.1400 \times 10^{-6}$	58.32	85.97	139.6
3	2070 / 29080	3150 / 43015	4910 / 70,250	7.836 / 46.148	10.08 / 66.41	18.903 / 111.9	3.89×10^{-6}	4.32×10^{-12}	604×10^{-12}	7.78×10^{-6}	$.1122 \times 10^{-6}$	51.18	75.03	124.64
2	1500 / 30580	2200 / 45215	3610 / 73860				1.025×10^{-6}	1.73×10^{-12}	209.5×10^{-12}	2.05×10^{-6}	$.0337 \times 10^{-6}$	42.7	62.7	103.07

A-103

APPENDIX B

FORMULAS USED



1.) $I_d = \dfrac{M(a^2+b^2)}{12}$

$I_e = \dfrac{M(4a^2+b^2)}{12}$

$I = \text{Ft lb SEC}^2$

M = MASS IN lbs.
a & b ~ EXPRESSED IN FT.
$g = 32.2$ FT/SEC²

2.) $T = \dfrac{\theta 2 I}{t^2}$

θ - IS THE ANGLE IN RADIANS AT A PARTICULAR TIME (t).

I = INERTIA

3.) $\alpha = \dfrac{2\theta}{t^2}$

WHERE α IS THE ACCELERATION AT A PARTICULAR ANGLE (θ) AND TIME (t).

α_1 - SHOWN FOR THE FIRST IMPACT ZONE AT STA 2519.

α_2 - TAKEN AT THE DRIFT ANGLE.

4.) $3g = (3)(32.2\,ft/sec^2) = 96.6\,ft/sec^2$

$\theta = \tfrac{1}{2}\alpha t^2$ OR $t = \left(\dfrac{2\theta}{\alpha}\right)^{1/2}$

CALC	KRISTOFFERSON	6-25-62	REVISED	DATE	UMBILICAL PLATFORM STUDY	
CHECK	J. KUNKLE	6-25-2				
APR						
APR					BOEING AIRPLANE COMPANY	PAGE 1

BAC 461 C-R4

CASE A - AS IS - SWING ARM, HORIZONTAL MOVEMENT.

$$I_e = \frac{M(4a^2+b^2)}{12} = \left(\frac{6467\#}{32.2\,ft/sec^2}\right)\frac{\left[(4)(40.8ft)^2+(4ft)^2\right]}{12} = \underline{120{,}500\,ft, lb, sec^2}$$

$$I_d = \frac{M(a^2+b^2)}{12} = \left(\frac{6467\#}{32.2\,ft/sec^2}\right)\left(\frac{(40.8ft)^2+(4ft)^2}{12}\right) = \underline{29{,}676\,ft, lbs, sec^2}$$

CONSIDERING A WIND DRAG OF 6.5 #/ft² OF AREA THE ARM MUST INITIALLY OVERCOME.

$$I_e = \left(\frac{8322\#}{32.2\,ft/sec^2}\right)\left[\frac{(4)(40.8\,FT)^2+(4ft)^2}{12}\right] = \underline{143{,}100\,ft, lbs, SEC^2}$$

$$Id = \left(\frac{8322\#}{32.2\,ft/sec^2}\right)\left[\frac{(4)(40.8ft)^2+(4ft)^2}{12}\right] = \underline{36{,}150\,ft, lbs, SEC^2}$$

$$T = \theta\frac{2I}{t}$$

$\theta = 12°$
$t = 1.6\,SEC$
$I = 120{,}500\,ft, lb, SEC^2$

$$= \frac{(12°)\left(\frac{2\pi}{180°}\right)(2)(120{,}500\,ft, lbs, Sec^2)}{(1.6\,SEC)^2}$$

$= \underline{39{,}440\,ft\,lbs\,\text{TORQUE}}$ FOR 12° MOVEMENT AT STA 2519

CALC	K[illegible]SON	6-25-[illegible]	REVISED	DATE	CASE A HORIZONTAL SWING ARM	
CHECK						
APR						
APR					BOEING AIRPLANE COMPANY	PAGE 2

$$T = \frac{2\Theta I}{t^2}$$

$\Theta = 69°$
$t = 7.5$ SEC.
$I = 120{,}500$ ft, lbs, SEC^2

$$= (2)(69°)\left(\frac{2\pi}{180°}\right)\frac{(120{,}500 \text{ ft, lbs, SEC}^2)}{(7.5\text{SEC})^2}$$

T $\underline{= 10{,}300 \text{ ft lbs torque}}$ FOR 69° MOVEMENT TO CLEAR DRIFT ANGLE

WITH WIND LOAD

$$T = \frac{2\Theta I}{t^2}$$

$\Theta = 12°$
$t = 1.6$SEC
$I = 143{,}100$ ft, lbs, SEC^2

$$= (2)(12°)\left(\frac{2\pi}{180°}\right)\frac{(143{,}100 \text{ ft, lbs, SEC}^2)}{(1.6\text{SEC})^2}$$

$T = \underline{46{,}850 \text{ ft-lbs torque}}$ FOR 12° MOVEMENT AS STA 2519 AGAINST WIND LOAD

$$T = \frac{2\Theta I}{t^2}$$

$\Theta = 69°$
$t = 7.5$ SEC
$I = 143{,}000$ ft, lbs, SEC^2

$$= (2)(69°)\left(\frac{2\pi}{180°}\right)\frac{(143{,}100 \text{ ft, lbs, SEC}^2)}{(7.5\text{ SEC})^2}$$

$T = \underline{12{,}230 \text{ ft-lbs torque}}$ FOR 69° MOVEMENT TO CLEAR DRIFT ANGLE AGAINST WIND LOAD.

CALC	KKSIDFFEKSON	6-25-64	REVISED	DATE	CASE A HORIZONTAL SWING ARM	
CHECK						
APR						
APR					BOEING AIRPLANE COMPANY	PAGE 3

$$\alpha_1 = \frac{2\theta}{t^2}$$

$\theta = 120$
$t = 1.6\,SEC$

$$\alpha_1 = \frac{(2)(120^\circ)}{(1.6\,SEC)^2} = \underline{9.4^\circ/SEC^2}$$

$$\alpha_2 = \frac{2\theta}{t^2}$$

$\theta = 69^\circ$
$t = 7.5\,SEC$

$$= \frac{(69^\circ)(2)}{(7.5\,SEC)^2}$$

$$\alpha_2 = \underline{2.46^\circ/SEC^2}$$

CALC	N.L.STREFFERSON	6-25-62	REVISED	DATE	CASE A HORIZONTAL SWING ARM	
CHECK						
APR						
APR					BOEING AIRPLANE COMPANY	PAGE 4

CASE B

LENGTH OF ARM ~ a = 43.4 ft = 520 INCHES.

WEIGHT = 11#/IN x 520 INCHES = 5720 #

TOTAL WEIGHT = 5720# + 1067# = 6787#

WIDTH ~ b = 4 ft

$$I_e = \frac{M(4a^2 + b^2)}{12}$$

$$= \left(\frac{6787\#}{32.2\,ft/sec^2}\right)\left[\frac{(4)(43.4ft)^2 + (4ft)^2}{12}\right]$$

I_e = 130,100 ft, lbs, SEC²

$$I_d = \frac{M(a^2 + b^2)}{12}$$

$$= \left(\frac{6787\#}{32.2\,ft/sec^2}\right)\left(\frac{(43.4ft)^2 + (4ft)^2}{12}\right)$$

I_d = 33,000 ft, lbs, SEC²

WITH WIND DRAG

$$I_e = \frac{M(4a^2 + b^2)}{12}$$

$$= \left(\frac{8738\#}{32.2\,ft/sec^2}\right)\left(\frac{(4)(43.4ft)^2 + (4ft)^2}{12}\right)$$

I_e = 169,500 ft, lbs, SEC²

CALC	KRISTOFFERSON	6-25-62	REVISED	DATE	CASE B HORIZONTAL SWING ARM (RELOCATED PIVOT POINT)	
CHECK						
APR						
APR					BOEING AIRPLANE COMPANY	PAGE 5

BAC 461 C-R4

$$I_d = \frac{M(a^2+b^2)}{12}$$

$$= \left(\frac{8738^{\#}}{32.2\ ft/sec^2}\right)\left(\frac{(43.4ft)^2 + (4ft)^2}{12}\right)$$

$$\underline{I_d = 42{,}470\ ft,\ lbs,\ sec^2}$$

$$T = \frac{2\theta I}{t^2}$$

T = TORQUE
$\theta = 3°$
$t = 1.6\ SEC$
$I = 130{,}100\ ft,\ lbs,\ sec^2$

$$= (2)(3°)\left(\frac{2\pi}{180°}\right)\left(\frac{130{,}100\ ft,\ lbs,\ sec^2}{(1.6\ sec)^2}\right)$$

$\underline{T = 11{,}080\ ft\text{-}lbs\ \text{TORQUE}}$ FOR 3° MOVEMENT AT STA 25A

$$T = \frac{2\theta I}{t^2}$$

$\theta = 42°$
$t = 7.5\ SEC$
$I = 130{,}100\ ft,\ lbs,\ sec^2$

$$= (2)(42°)\left(\frac{2\pi}{180°}\right)\left(\frac{130{,}100\ ft,\ lbs,\ sec^2}{(7.5\ sec)^2}\right)$$

$T = \underline{6{,}440\ ft\ lbs\ \text{TORQUE}}$ FOR 42° MOVEMENT TO CLEAR DRIFT ANGLE

WITH WIND DRAG

$$T = \frac{2\theta I}{t^2}$$

$\theta = 3°$
$t = 1.6\ SEC$
$I = 169{,}500\ ft,\ lbs,\ sec^2$

$$= (2)(3°)\left(\frac{2\pi}{180°}\right)\left(\frac{169{,}500\ ft\ lbs\ sec^2}{(1.6\ sec)^2}\right)$$

$T = \underline{15{,}270\ ft\ lbs\ \text{TORQUE}}$ FOR 3° MOVEMENT AT STA 2519 AGAINST WIND DRAG

CALC	KRISTOFFERSON	6-25-6?	REVISED	DATE	CASE B	
CHECK					HORIZONTAL SWING ARM (RELOCATED PIVOT POINT)	
APR						
APR					BOEING AIRPLANE COMPANY	PAGE 6

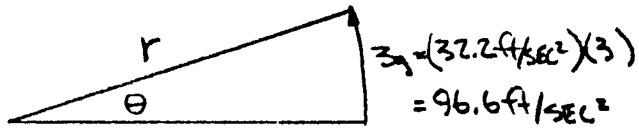
$$T = \frac{2\theta I}{t^2}$$

$\theta = 42°$
$t = 7.5$ SEC
$I = 169{,}500$ ft lbs SEC^2

$$= (2)(42°)\left(\frac{2\pi}{180°}\right)\left(\frac{169{,}500 \text{ ft lbs sec}^2}{12}\right)$$

$T = \underline{8{,}330 \text{ Ft lbs TORQUE}}$ FOR 42° MOVEMENT TO CLEAR DRIFT ANGLE AGAINST WIND DRAG.

TIME REQUIRED TO CLEAR STA 2519 WITH 3G ACCELERATION



$$\theta = \tfrac{1}{2}\alpha t^2$$

$\theta = 3°$
$\alpha = r\ell = (96.6 \text{ ft/sec}^2)(43.4 \text{ ft}) = 4200 \text{ FAD/sec}^2$
$r = 43.4$ ft

$$t = \sqrt{\frac{2\theta}{\alpha}}$$

$$= \sqrt{\frac{(2)(3°)}{4200 \text{ ft}^2/\text{sec}^2}\left(\frac{2\pi}{180°}\right)}$$

$\underline{t = .0224 \text{ SECONDS}}$

$\theta = 3°$
$t = 1.8$ SEC

$$\alpha_1 = \frac{2\theta}{t^2}$$

$$\alpha_1 = \frac{(2)(3°)}{(1.8\text{SEC})^2} = \underline{2.34°/\text{SEC}^2}$$

$\theta = 42°$
$t = 7.8$ SEC

$$\alpha_2 = \frac{2\theta}{t^2}$$

$$\alpha_2 = \frac{(2)(42°)}{(7.8\text{SEC})^2} = \underline{1.49°/\text{SEC}^2}$$

CALC	KRISTOFFERSON	6-15-62	REVISED	DATE	CASE B HORIZONTAL SWING ARM (RELOCATED PIVOT POINT)
CHECK					
APR					
APR					BOEING AIRPLANE COMPANY
					PAGE 7

BAC 461 C-R4

CASE C

WEIGHT = 6467 #
LENGTH b = 40.8 ft
WIDTH a = 4 ft

$$I_e = \frac{M(4a^2+b^2)}{12}$$

$$= \left(\frac{6467\#}{32.2\,ft/sec^2}\right)\left[\frac{(4)(40.8\,ft)^2 + (4\,ft)^2}{12}\right]$$

$$\underline{I_e = 120{,}500\ ft, lbs, sec^2}$$

$$I_d = \frac{M(a^2+b^2)}{12}$$

$$= \left(\frac{6467\#}{32.2\,ft/sec^2}\right)\left(\frac{(40.8\,ft)^2 + (4\,ft)^2}{12}\right)$$

$$\underline{I_d = 30{,}125\ ft, lbs, sec^2}$$

$$T = \frac{2\theta I}{t^2}$$

$\theta = 25°$
$t = 1.8$ SEC
$I = 120{,}500$ ft lbs sec^2

$$= (2)(25°)\left(\frac{2\pi}{180°}\right)\left(\frac{120{,}500\ ft\ lbs\ sec^2}{1.8^2}\right)$$

T = $\underline{64{,}800\ ft\ lbs\ TORQUE}$ FOR 25° MOVEMENT AT STA 2519

CALC	KRISTOFFERSON	6-25-62	REVISED	DATE	CASE C TRACK - VERTICAL MOTION	
CHECK						
APR					BOEING AIRPLANE COMPANY	PAGE 8
APR						

CASE D

WEIGHT = 6467 #

LENGTH a = 40.8 ft

WIDTH b = 4 ft

$$I_e = \frac{M(4a^2 + b^2)}{12}$$

$$= \left(\frac{6467\#}{32.2\,ft/sec^2}\right)\left[\frac{(4)(40.8ft)^2 + (4ft)^2}{12}\right]$$

$$I_e = \underline{120{,}500\ ft,\ lbs,\ sec^2}$$

$$I_d = \frac{M(a^2 + b^2)}{12}$$

$$= \left(\frac{6467\#}{32.2\,ft/sec^2}\right)\left(\frac{(40.8ft)^2 + (4ft)^2}{12}\right)$$

$$I_d = \underline{30{,}125\ ft\ lbs\ sec^2}$$

$$T = \frac{2\theta I}{t^2}$$

$\theta = 240$

$t = 1.2$ SEC

$I = 120{,}500$ ft lbs sec^2

$$= (2)(240)\left(\frac{2\pi}{180°}\right)\left(\frac{120{,}500\ ft\ lbs\ sec^2}{12}\right)$$

$T = \underline{131{,}000\ ft\ lbs\ TORQUE}$ FOR 240° MOVEMENT AT STA 2519

CALC	KRISTOFFMAN	6-25-62	REVISED	DATE	CASE D GRAVITY DROP TRACK CONTROL
CHECK					
APR					
APR					BOEING AIRPLANE COMPANY

$$T = \frac{2\theta I}{t^2}$$

$\theta = 68°$
$t = 6.75$ SEC
$I = 120{,}500$ ft lbs SEC^2

$$= (2)(68°)\left(\frac{2\pi}{180°}\right)\left(\frac{129{,}500 \text{ ft lbs SEC}^2}{1.2}\right)$$

T = 12,590 ft lbs TORQUE FOR 68° MOVEMENT TO CLEAR DRIFT ANGLE

$$\alpha_1 = \frac{2\theta}{t^2}$$

$\theta = 24°$
$t = 1.2$ SEC

$$= \frac{(2)(24°)}{(1.2 \text{ SEC})^2}$$

$$\alpha_1 = 31.2 °/\text{SEC}^2$$

$$\alpha_2 = \frac{2\theta}{t^2}$$

$\theta = 68°$
$t = 6.75$ SEC

$$= \frac{(2)(68°)}{(6.75 \text{ SEC})^2}$$

$$\alpha_2 = 2.99 °/\text{SEC}^2$$

CALC	KRISTOFFERSON	6-25-62	REVISED	DATE	CASE D GRAVITY DROP TRACK CONTROL	
CHECK						
APR						
APR					BOEING AIRPLANE COMPANY	PAGE 11

CASE E

a = ACCELERATION ~ ft/sec^2
S = distance ~ ft
t = 1.6 SEC

$$a_1 = \frac{2S}{t^2}$$

$$= \frac{(2)\,140\,\text{IN}}{(12\,\text{IN/ft})(1.6\,\text{SEC})^2}$$

a_1 = $\underline{4.56\ \text{ft/SEC}^2}$ TO CLEAR STA 2519

S = 245 IN
t = 7.25 SEC

$$a_2 = \frac{2S}{t^2}$$

$$= \frac{(2)(245\,\text{IN})}{(12\,\text{IN/ft})(7.25\,\text{SEC})^2}$$

a_2 = $\underline{.778\ \text{ft/SEC}^2}$ TO CLEAR DRIFT ANGLE

CASE F

a_1 = CASE E a_1 = $\underline{4.56\ \text{ft/SEC}^2}$ TO CLEAR STA 2519

$\theta = 62°$
t = 6.75 SEC

$$\alpha_2 = \frac{2\theta}{t^2}$$

$$= \frac{(2)(62°)}{(6.75\,\text{SEC})^2}$$

α_2 = $\underline{2.21\ °/\text{SEC}^2}$ NOTE: 1 G AVAILABLE FOR α_2

CALC	KRISTOFFERSON	6-25-62	REVISED	DATE	CASE E HORIZONTAL RETRACTION CASE F RETRACTION & DROP	
CHECK						
APR						
APR						
					BOEING AIRPLANE COMPANY	PAGE 12

CASE G

WEIGHT = 7557#

LENGTH a = 49.2 ft

WIDTH b = 4 ft

$$I_e = \frac{M\,(4a^2+b^2)}{12}$$

$$= \left(\frac{7557\,\#}{32.2\,ft/sec^2}\right)\left[\frac{(4)(49.2\,ft)^2 + (4\,ft)^2}{12}\right]$$

$$I_e = \underline{189{,}100 \text{ ft lbs sec}^2}$$

$$I_d = \frac{M\,(a^2+b^2)}{12}$$

$$= \left(\frac{7557\,\#}{32.2\,ft/sec^2}\right)\left(\frac{(49.2\,ft)^2 + (4\,ft)^2}{12}\right)$$

$$I_d = \underline{47{,}275 \text{ ft lbs sec}^2}$$

$$T = \frac{2\theta I}{t^2}$$

$\theta = 14°$

$t = 1.8$ sec

$I = 189{,}100$ ft lbs sec^2

$$= (2)(14°)\left(\frac{2\pi}{180°}\right)\left(\frac{189{,}100 \text{ ft lbs sec}^2}{1.8^2}\right)$$

$T = \underline{57{,}000 \text{ ft lbs torque}}$ TO CLEAR STA 2519

CALC	KRISTOFFERSON 6-25-62	REVISED	DATE	CASE G VERTICAL MOVEMENT	
CHECK					
APR					
APR				BOEING AIRPLANE COMPANY	PAGE 13

$$T = \frac{2\theta I}{t^2}$$

$\theta = 45^\circ$
$t = 7.8\,SEC$
$I = 189{,}100\ ft\ lbs\ SEC^2$

$$= (2)(45^\circ)\left(\frac{2\pi}{180^\circ}\right)\left(\frac{189{,}100\ ft\ lbs\ SEC^2}{12}\right)$$

$T =$ 18,300 ft lbs TORQUE TO CLEAR DRIFT ANGLE

$$\alpha_1 = \frac{2\theta}{t^2}$$

$\theta = 14^\circ$
$t = 1.8\,SEC$

$$= \frac{(2)(14^\circ)}{(1.8\,SEC)^2}$$

$$\alpha_1 = 8.65^\circ/SEC^2$$

$$\alpha_2 = \frac{2\theta}{t^2}$$

$\theta = 45^\circ$
$t = 7.8\,SEC$

$$= \frac{(2)(45^\circ)}{(1.8\,SEC)^2}$$

$$\alpha_2 = 1.48^\circ/SEC^2$$

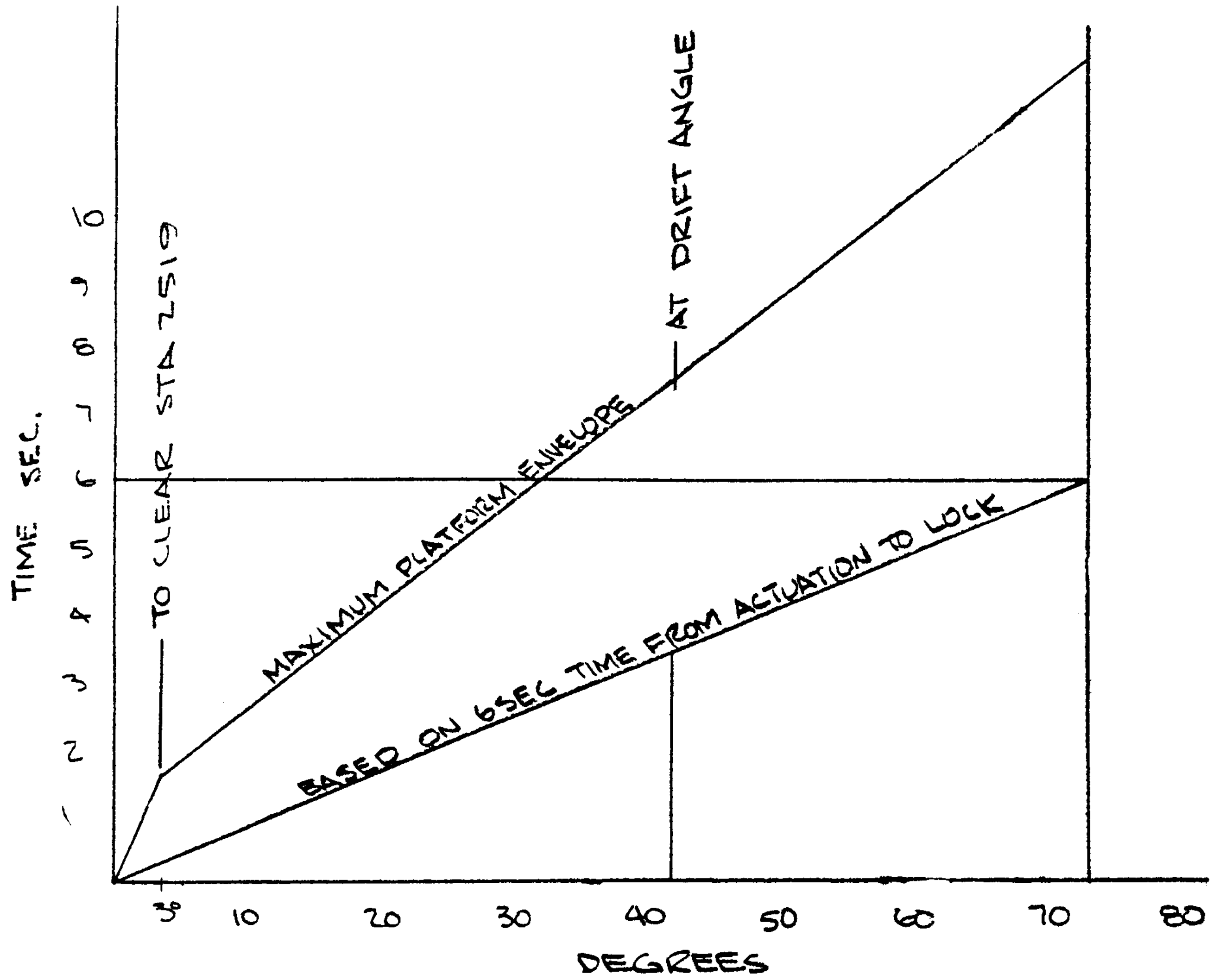
CALC KRISTOFFERSON 6-15-62	REVISED	DATE	CASE G VERTICAL MOVEMENT	
CHECK				
APR				
APR			BOEING AIRPLANE COMPANY	PAGE 14

CALC	KRISTOFFERSON	6-15-6?	REVISED	DATE
CHECK				
APR				
APR				

CASE B
HORIZONTAL SWING ARM
(RELOCATED PIVOT POINT)

BOEING AIRPLANE COMPANY

PAGE 15



CASE B
RELOCATION OF PIVOT
-HORIZONTAL SWING-

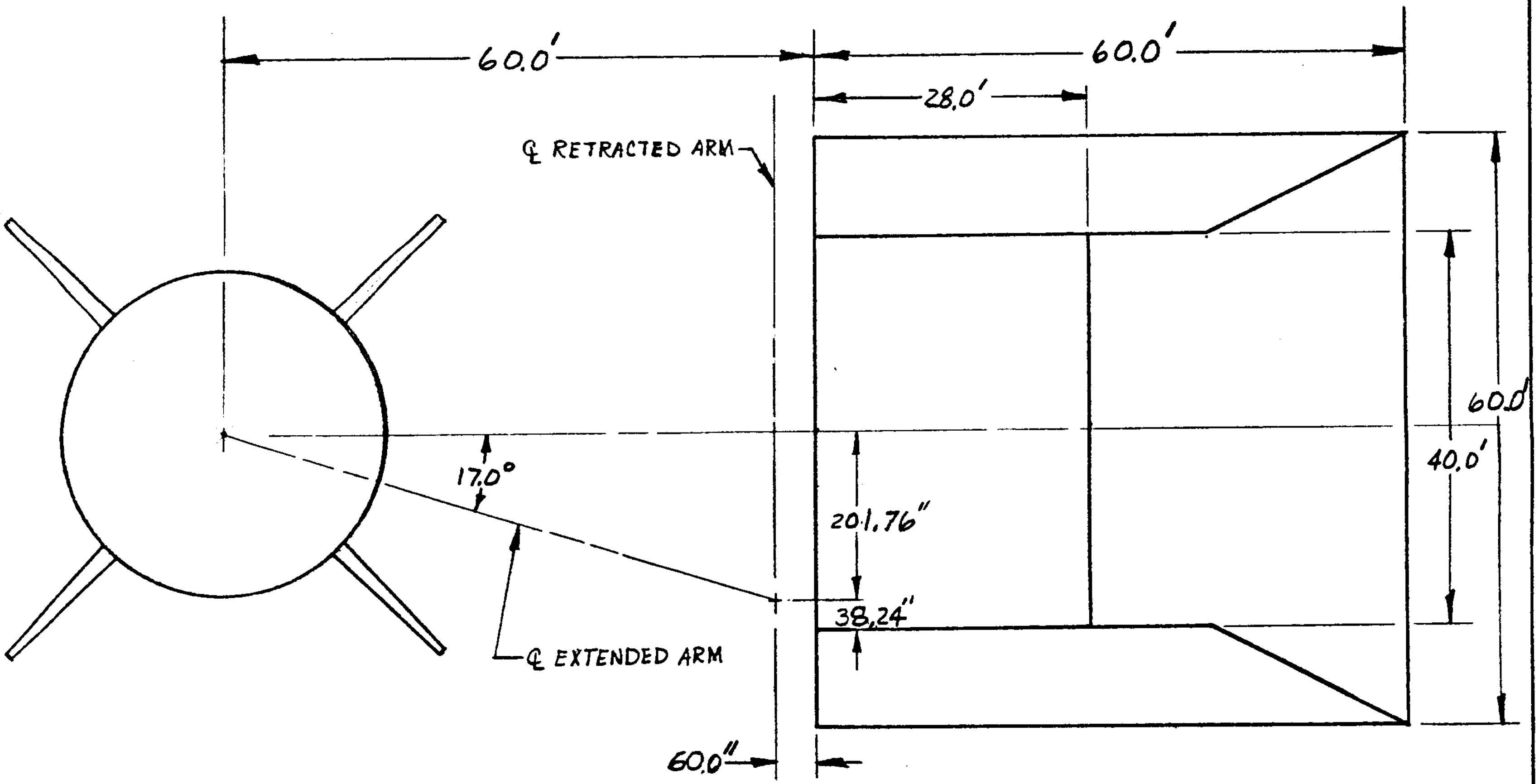
BAC 461 C-R4

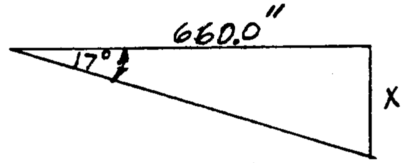
PREPARED BY LARAMORE
CHECKED BY SWH
REVISED BY

BROWN ENGINEERING COMPANY, INC.
P. O. BOX DRAWER 917
PHONE JE 6-5536
HUNTSVILLE, ALABAMA

PAGE 1
REPORT NO.
DATE

LOCATION OF ROTARY ACTUATOR GEOMETRY





$X = (660)(\tan 17°)$

$X = (660)(.3057)$

$X = 201.76''$

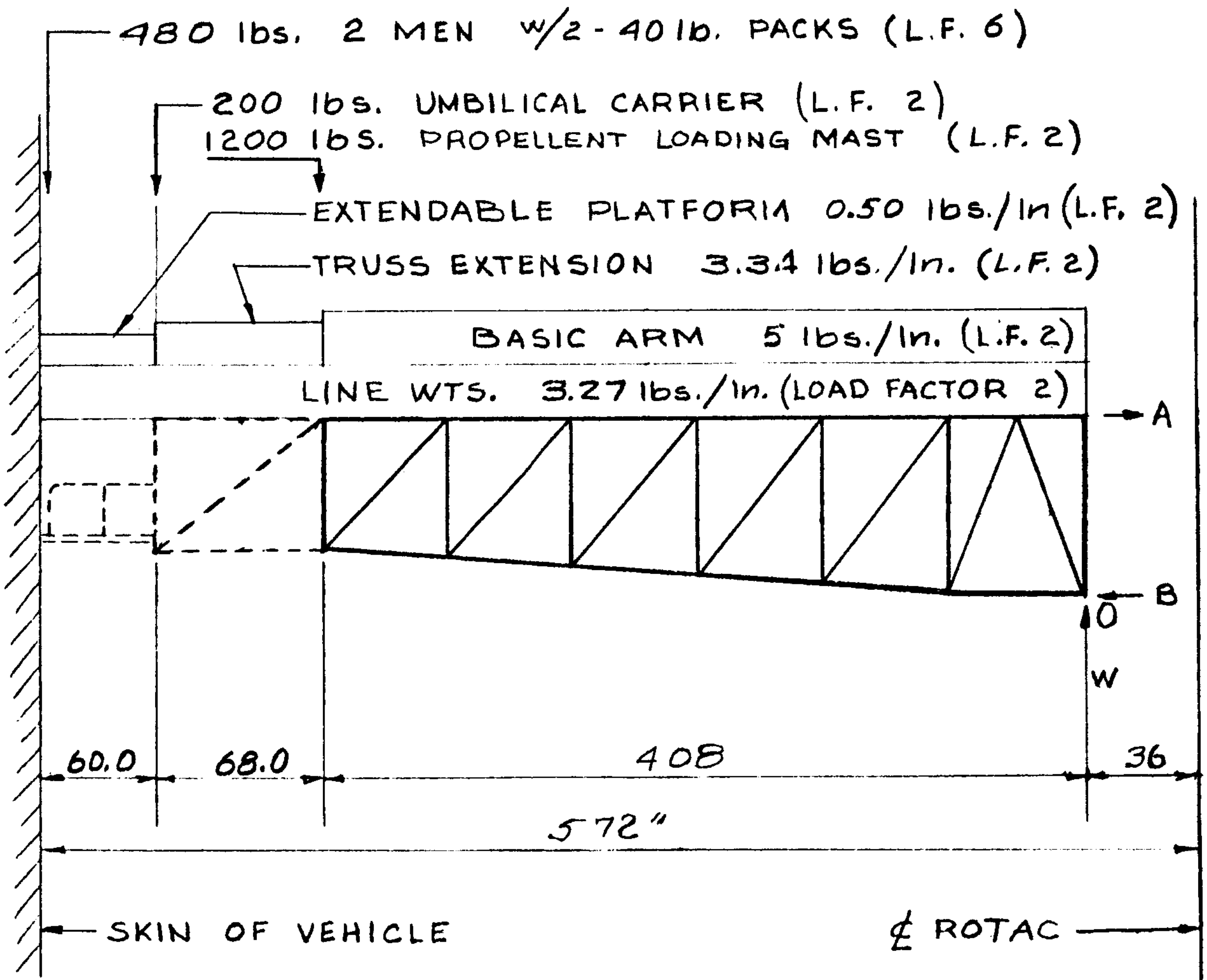
$240.00'' - 201.76'' = 38.24''$

∴ ℄ ROTAC IS LOCATED 60.0" FROM TOWER FACE & 201.76" FROM ℄ OF TOWER

SERVICE ARMS

BASIC TRUSS LOADS (VERTICAL)

L.F. = LOAD FACTOR



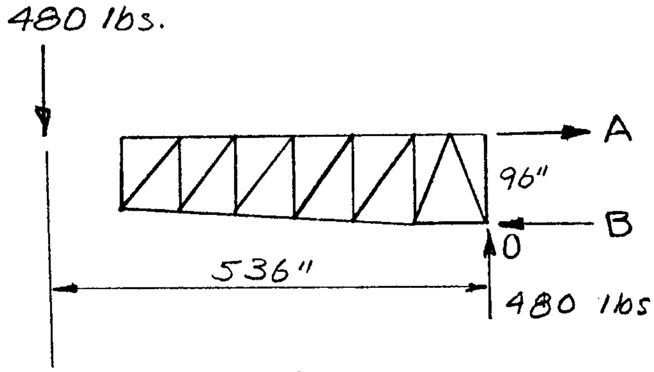
S-IVB

ESTIMATE SIZE OF TOP & BOT CHORD

STRESSES TO CONSIDER : LIVE LOAD
DEAD LOAD
WIND LOAD
LATERAL LOAD DUE TO ANGULAR ACCELERATION

I LIVE LOAD

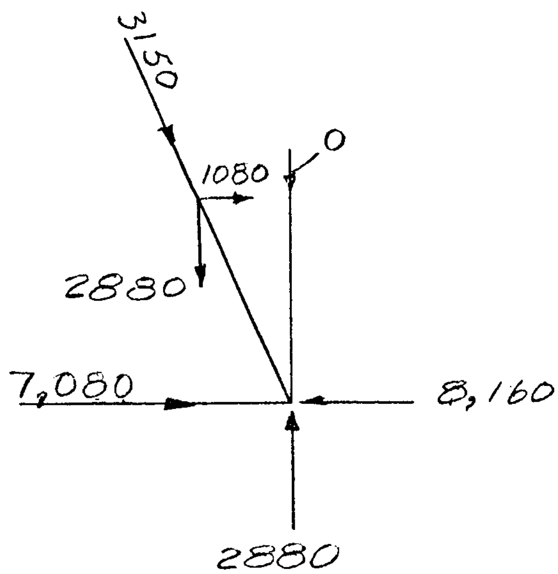
2 MEN WITH 2 40 lb. PACKS (SEE PAGE 1)



$\Sigma M_O = 0 \qquad A \,\&\, B = \dfrac{(480)536}{96} = 2{,}680$ lbs.
$= 1{,}360$ lbs / MEMBER

USE LOAD FACTOR OF 6, FORCE = 8,160 lbs.

ISOLATE JOINT 0



S IVB

II DEAD LOAD (SEE LOADING ON PAGE 1)

$$\begin{aligned}
& 200\,(476) && = 95{,}200 \\
\Sigma M_o = \; & 1200(408) && = 490{,}000 \text{ in-lbs.} \\
& 0.50(60)(508) && = 15{,}250 \\
& 3.34(68)(442) && = 100{,}300 \\
& 5(408)(204) && = 416{,}000 \\
& 3.27(536)(268) && = 469{,}000 \\
& && M_o = 1{,}585{,}750 \text{ in. lbs.}
\end{aligned}$$

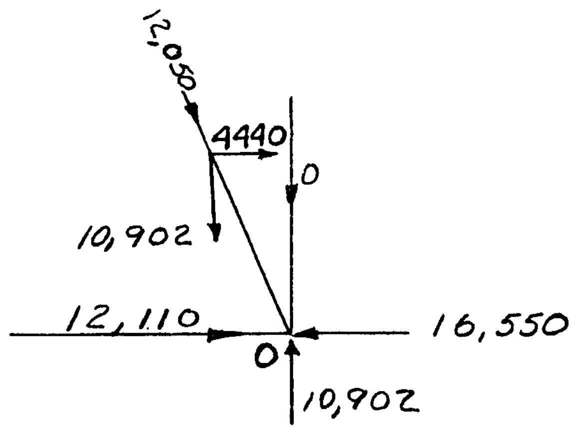
$$A \,\&\, B = \frac{1{,}585{,}750}{96} = 16{,}550 \text{ lbs.} = 8{,}275 \text{ lbs/MEMBER}$$

USE LOAD FACTOR OF 2, FORCE = 16,550 lbs./MEMBER

TOTAL DEAD LOAD = 5,452 lbs

C. OF G = 291 IN. FROM END OF TRUSS (JOINT O)

ISOLATE JOINT O



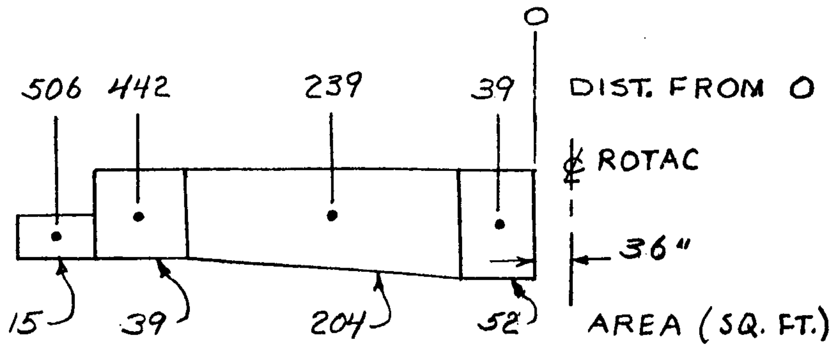
III WIND LOAD

CHECK FOR LAUNCH WIND AT EL. 330'-0"

V = 60 MPH = 88 FPS

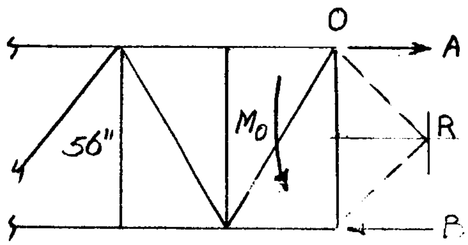
$$q = \rho \frac{V^2}{2} = 0.002378\,\frac{(88)^2}{2} = 9.2 \text{ PSF}$$

S-IV B



ΣM @ O

$9.2\,(52)(39) = 18{,}650$
$9.2\,(204)(239) = 448{,}000$
$9.2\,(39)(442) = 158{,}500$
$9.2\,(15)(506) = 69{,}800$
$M_O = 694{,}950$ lb-in.



A & B = $\dfrac{694{,}950}{56}$ = 12,400 lb.

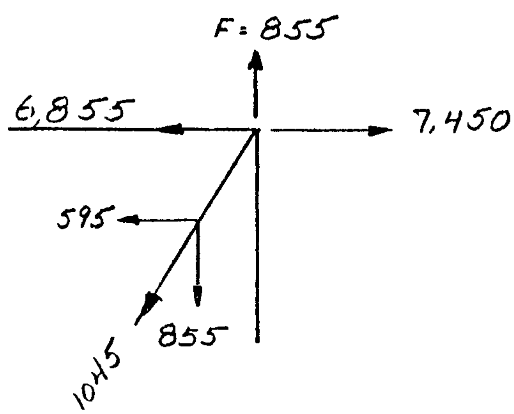
LOAD FACTOR = 2

FORCE = 24,800 lb

ASSUME 60% EFFECTIVE, FORCE = 14,900 lb.
= 7,450 lb/MEMBER

TOT. WIND FORCE = 1,710 lb. (2850 × 60%)
C OF G = 244 IN. FROM O

ISOLATE JOINT O



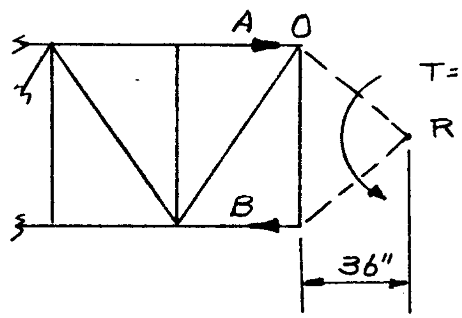
S-II & S-IV B

IV INVESTIGATE LOADS DUE TO ANGULAR ACCELERATION

FROM APPENDIX PAGE 21 & 23

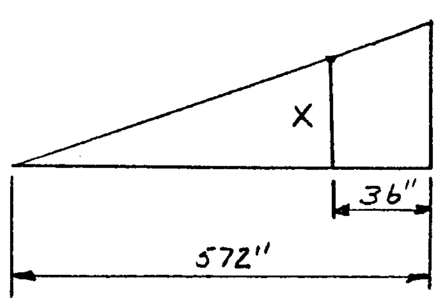
TORQUE FOR MAX. ACCELERATION AT ROTAC
= 710,000 IN-LBS.

TORQUE FOR MAX. DECELERATION AT ROTAC
= 960,000 IN-LBS.
(INCLUDES WIND)



T = 1,920,000 IN-LBS.

USE LOAD FACTOR OF 2
∴ T = 1,920,000 IN-LBS.
FOR S-II ARM



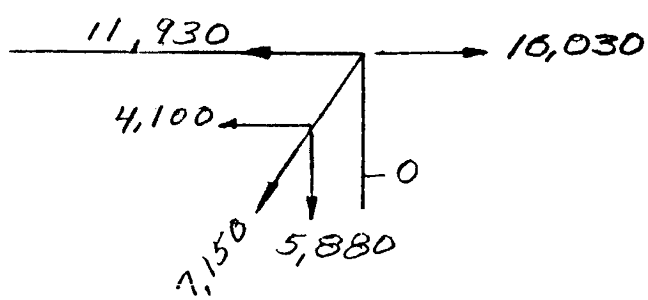
1,920,000 IN-LBS

$$\frac{X}{1{,}920{,}000} = \frac{536}{572}$$

X = 1,797,000 IN-LBS.

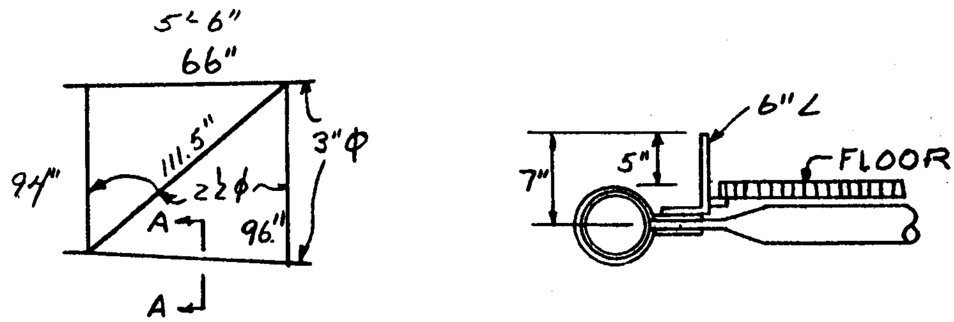
FORCE A & B = $\frac{1{,}797{,}000}{56(2)}$ = 16,030 lbs

ISOLATE JOINT O



SOLIDITY RATIO OF S-II ARM

ISOLATING AN AVERAGE PANEL OF THE ARM



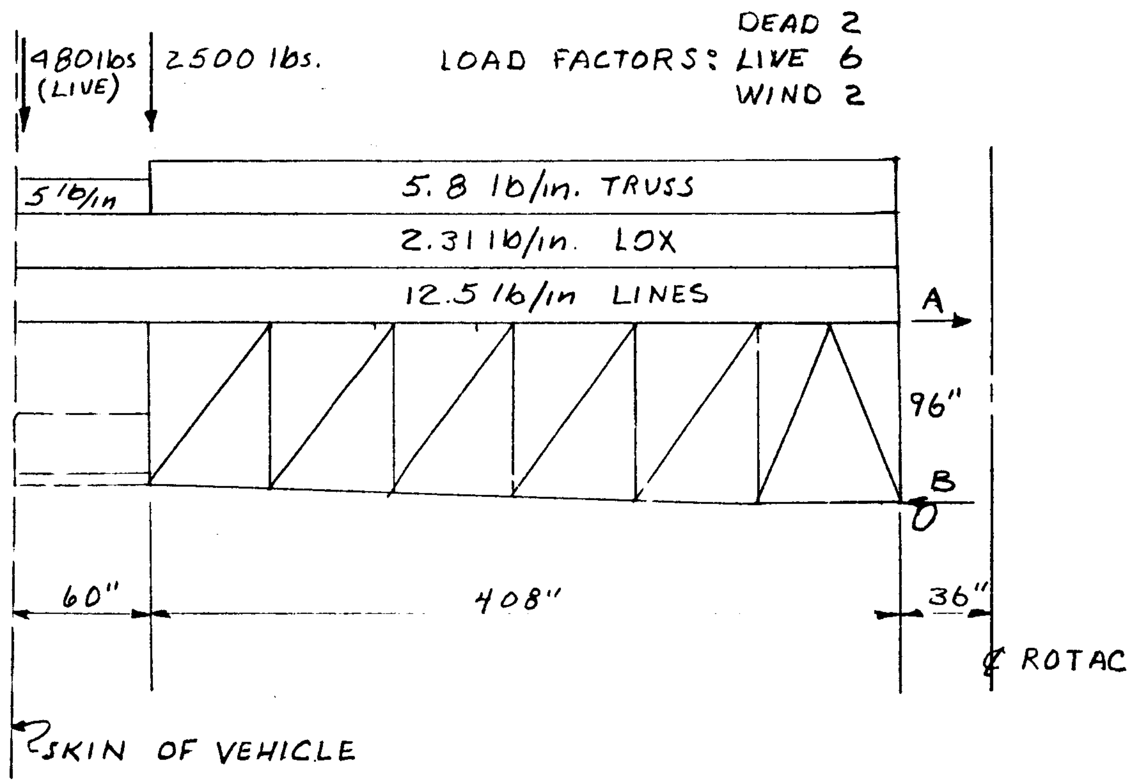
TOTAL AREA = 95(66) = 6270 SQ. IN.

1" x .08" ϕ WIRE MESH	A = 16% OF TOT	=	1000 SQ. IN.
2 - 3" ϕ x 66" TUBES	3 X 132"	=	396
301" OF $2\frac{1}{2}$" ϕ TUBE	2.5 X 301"	=	753
6" L W/5" PROJ.	5 X 66	=	330
$1\frac{1}{4}$" ϕ HANDRAIL	1.5 X 66	=	99
SERVICE LINES	66 X 31.5/2	=	1040
			3618 SQ. IN.

$$\text{SOLIDITY RATIO} = \frac{3618}{6270} \times 100 = 57.7\%$$

SAY 60%

INVESTIGATE TOP & BOT. CHORD OF S-2 TRUSS.



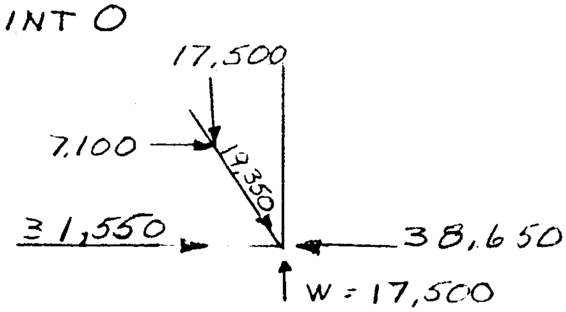
ΣM_O

480(468)(6)	=	1,347,000
2500(408)(2)	=	2,040,000
5(60)(438)(2)	=	262,600
18.3(468)(234)(2)	=	3,252,000
5.8(408)(204)(2)	=	566,000

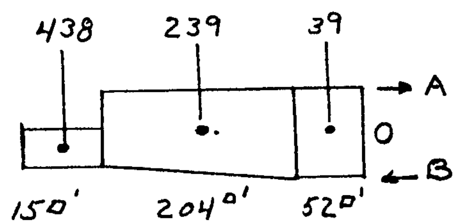
$M_O =$ 7,417,600 in/lbs. (D.L. + L.L.)

$A + B = \dfrac{7,417,600}{96} = 77,300$ lbs
$= 38,650$ lbs/TRUSS

ISOLATE JOINT O



WIND LOAD ON S-2 ARM



V @ 140 FT. EL. = 71.5 FPS

q = 6.06 PSF

M_O = 52 (39)(6.06) = 12,270
204 (239)(6.06) = 295,000
15 (438)(6.06) = 39,930

M_O = 347,200 in/lbs.

M_O = 347,200 × 2 × 60% (EFF.) = 417,000 IN/lbs.

$A + B = \frac{417{,}000}{56} = 7{,}440$ lbs.

Σ FORCES L.L. + D.L. + WIND	Σ FORCES FOR ∠ ACC.
MAX. TENSION = 46,010 lbs.	MAX. TEN. = 47,680
MAX COMP. = 38,990 lbs.	MAX COMP = 47,680

TRY 3 ⌀ × 7/16" WALL

a = 3.522 SQ. IN. w = 4.15 lb/FT. r = 0.9191 in.

$\frac{K\ell}{r} = \frac{78}{0.9191} = 85.0 > C$ ∴ $f_c = 14.73$ KSI

P/A = 13.5 KSI w/LOAD FACTOR OF 2

ACT. P/A = 13.5/2 = 6.75 KSI

SAFETY FACTOR = 14.73/6.75 = 2.18

S-IVB ARM (ASSUME 40% WIND EFFECT)

+ = TENSION
− = COMPRESSION
FOR SIVB ARM

Σ FORCES IN TOP CHORD

STATIC LOADS

L.L. = (+) 8,160 lbs.
D.L. = (+) 16,550 lbs.
WIND = (±) 7,450 lbs

MAX = (+) 32,160 lbs.

MIN = (+) 17,260 lbs

ANGULAR ACCELERATION LOADS

D.L. = (+) 16,550 lbs.
$\angle$ ACC. = (±) 13,300 lbs. (INCLUDES WIND)

MAX. = (+) 29,850 lbs

MIN. = (+) 3,250 lbs

Σ FORCES BOTTOM CHORD

STATIC LOAD	$\angle$ ACC LOADS
L.L. = (−) 7,080 lbs.	D.L. = (−) 12,110 lbs.
D.L = (−) 12,110	$\angle$ ACC. = (±) 11,520
WIND = (±) 7,450	
MAX = (−) 26,640 lbs.	MAX = (−) 23,630 lbs
MIN = (−) 11,740 lbs.	MIN - (−) 590 lbs.

S-IV B ARM

MAX. TOP CHORD LOAD = +32,160 lbs.

MAX. BOTTOM CHORD LOAD = −26,640 lbs

THE ABOVE LOADS INCLUDE THE FOLLOWING LOAD FACTORS

L.L. 6

D.L. 2

WIND 2

∠ ACC. 2

INVESTIGATE ALUMINUM TUBING OF GRADES.

7075-T6 & 2014-T6

2014-T6 $YS_T = 53$ KSI $YS_c = 55$ KSI $B = 61.4$ $D = 0.410$ $C = 50$

7075-T6 $YS_T = 72$ KSI $YS_c = 72$ KSI $B = 81.7$ $D = 0.629$ $C = 43$

TRY 3" ϕ x ¼" WALL A = 2.160 SQ. IN. r = 0.976 IN.

$$\frac{Kl}{r} = \frac{1(78)}{0.976} = 79.9 > C \quad \therefore f_c = 16.0 \text{ KSI}$$

$$P/A = \frac{26,640}{2.160} = 12.2 \text{ KSI} \qquad S.F._{BUCKLING} = \frac{16.0}{12.2} = 1.31$$

SAFETY FACTOR$_B$ = 1.31 FOR BOTH 7075-T6 & 2014-T6

CHECK S.F. FOR TENSION

$$P/A = 32,160/2.160 = 14.9 \text{ KSI}$$

$S.F._{2014-T6} = 3.56$ $S.F._{7075-T6} = 4.83$ 2.36 6061-T6

$$MIN.\ r = \frac{78}{150} = 0.51 \text{ IN.} \quad \therefore O.K.$$

INVESTIGATE DIAGONALS:-

FOR TENSION MEMBERS MIN. $\frac{l}{r} = 150$

$$\text{MIN. } r = \frac{114}{150} = 0.761 \text{ IN.}$$

$\therefore$ $2\frac{1}{2}"\phi$ TUBE MIN. SIZE ($\frac{3}{16}"$ WALL)

FOR COMPRESSION MEMBERS ($3"\phi \times \frac{1}{4}"$ WALL)

$$\frac{Kl}{r} = \frac{1(106)}{0.976} = 109 \quad > C = 44(7075\text{-}T6) + 50(2014\text{-}T6)$$

$\therefore f_s = 8585$ PSI $\quad \Sigma$ FORCES = 15,200 lbs. COMP.

$$\frac{P}{A} = \frac{15,200}{2.1598} = 7.05 \text{ PSI}$$

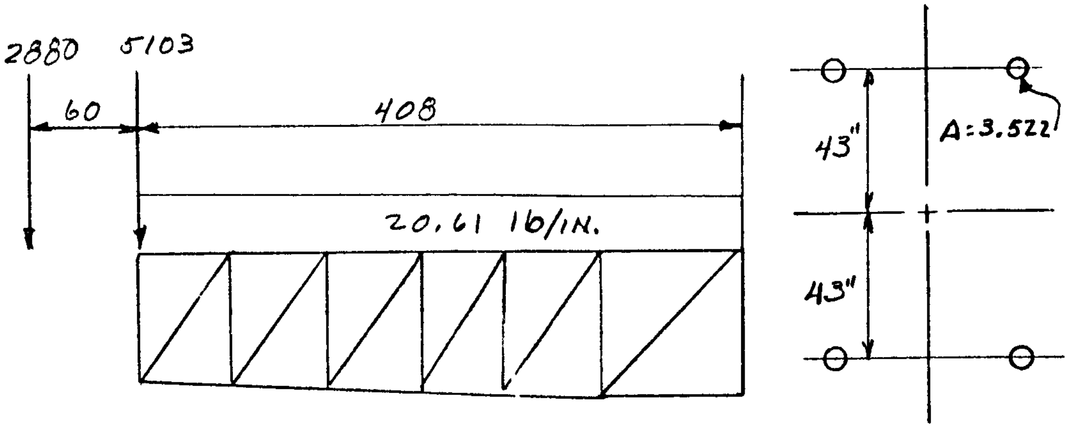
S.F = 1.22 (COMP.)

FOR TENSION ($2\frac{1}{2}"\phi \times \frac{3}{16}"$ WALL)

$$\frac{P}{A} = 11,150 \text{ PSI} \qquad FS = 4.75(2014\text{-}T6) = 6.46(7075\text{-}T6)$$

INVESTIGATE DEFLECTION OF TRUSS OF S II ARM

TRUSS TO BE EXAMINED AS A BEAM WITH A SECTION LIKE THAT OF THE TRUSS AT THE FAR END. THE MOMENT OF INERTIA OF THE CHORD MEMBERS ONLY WILL BE USED



$I = 3.522(43)^2 4 = 26,100 \text{ IN}^4$

$E = 10,600,000 \text{ lb/IN}^2$

TOT. Δ = Δ FOR UNIFORM LOAD + Δ FOR POINT LOADS.

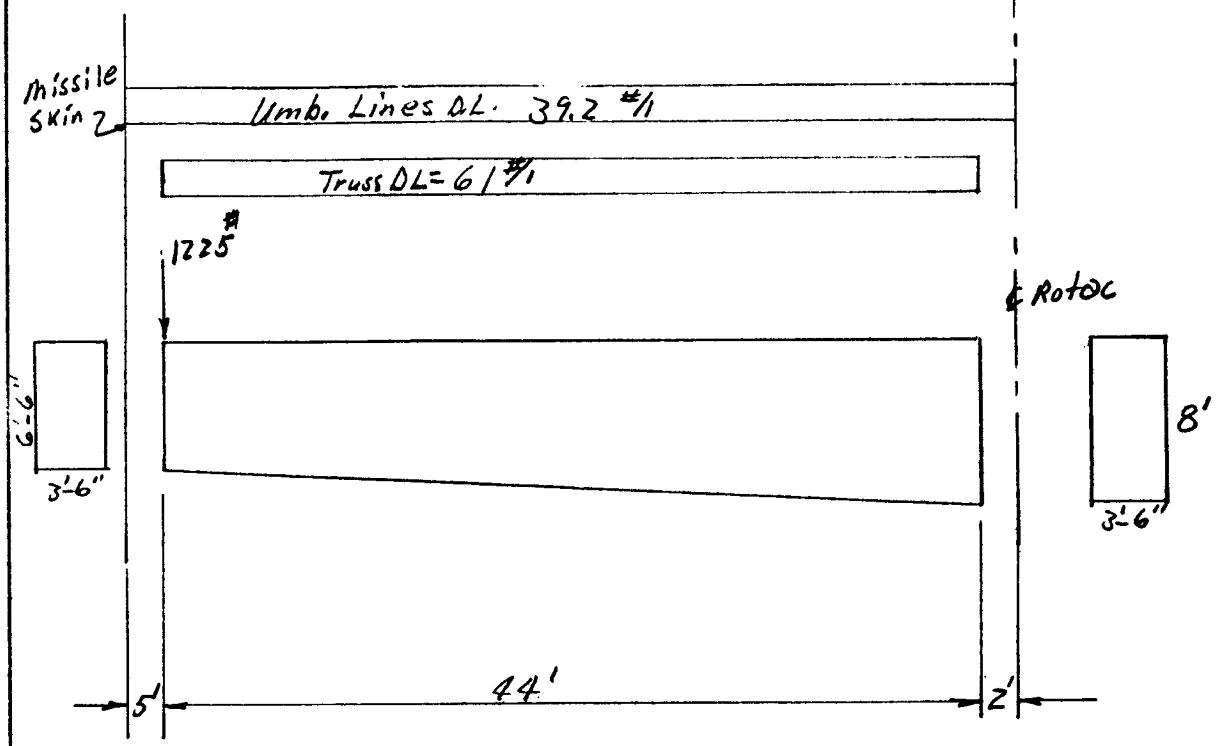
$$= \frac{w\ell^4}{8EI} + \frac{P_1\ell^3}{3EI} + \frac{P_2\ell^3}{3EI}$$

$$= \frac{20.61(408)^4}{8(10,600,000)(26,100)} + \frac{2880(468)^3}{3(10,600,000)(26,100)} + \frac{5103(408)^3}{3(10,600,000)(26,100)}$$

$$= .256 + .356 + .284$$

TOT Δ = 0.896 IN SAY 0.9 IN.

S-IVB Aft Umbilical Arm



Retarding force of wind —

@ 225' Level wind velocity = 47 knots @ 200'
" " = 51.1 " @ 300'

Say @ 225' level wind velocity = 48 knots = 81.0 ft/sec

$q = \frac{\rho v^2}{2} = \frac{.002378(81)^2}{2} = 7.8$ psf

$P = qA = 7.8\left(\frac{1}{2}\right)(\overset{14.5}{6.5+8})(44.0) = 2490^{\#}$

Assume wind acts halfway out arm or $2 + \frac{44}{2} = 24$

M @ ℄ Rotac = 2490(24) = 59,700 ft-lb = 717,000 in.-lb

Assume 40% "plate effect" = 287,000 in.-lb

Truss Loading

Umbilical Lines and 1200# Propellant Loading mast plus 25# Retractable platform —

$$I_{m_{hinge}} = 39.2(47)\left(\frac{47}{2}\right)^2 + 4(39.2)(47)^2 + 1225(46)^2$$

$$= 1,017,465 + 346,371 + 2,592,100 = 3,955,936$$

$$I_M = \frac{I_m}{g} = \frac{3,955,936}{32.2} = 122,855 \text{ lb-ft-sec}^2$$

Truss Dead Load –

$$I_{m_{hinge}} = 61(44)(24)^2 = 1,600,000$$

$$I_M = \frac{I_m}{g} = \frac{1,600,000}{32.2} = 49,700 \text{ lb-ft.sec}^2$$

$$\Sigma I_M = \Sigma \frac{I_m}{g} = 122,855 + 49,700 = 172,555 \text{ lb-ft-sec}^2 = 2,070,000 \text{ lb-in-sec}^2$$

Torque calculations

Total Torque required is the torque req'd to overcome the wind moment plus that req'd to overcome the inertia effect.

Wind moment – = 287,000 in. lb
Inertia Effect –

$$T = I_M \alpha \quad ; \quad \alpha = \frac{2\theta}{t^2}$$

$$\therefore T = \frac{I_M 2\theta}{t^2} = \frac{2,070,000(2)(\theta)}{t^2} = 4,140,000 \frac{\theta}{t^2}$$

Collision course #1 (upper taper) – $\theta = 3°$; $t = 1.5$ sec.
Collision course #2 (fin) – $\theta = 52°$; $t = 7.2$ sec.

PREPARED BY Perrigin **BROWN** ENGINEERING COMPANY, INC. PAGE 15
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REVISED BY DATE 6/8/62
P. O. BOX DRAWER 917
PHONE JE 6-5536
HUNTSVILLE, ALABAMA

S-IV B Aft Umbilical Arm

Torque calculations (Cont.)

It has been decided that a time factor of safety of 2 is not necessary. Now, in the torque calculations, the actual time of swing for the arm to clear the vehicle should be used and the resulting torque doubled. Too, it has been decided that, since the critical direction of wind at launch is almost parallel to the arm, the torque req'd to overcome wind would be almost negligible. However, should the wind not be blowing in the critical direction, but be perpendicular to the arm, the torque must still overcome the wind and have the arm out of the way of the blast when the tail of the vehicle comes by.

Torque req'd to move Arm into Launch wind

Wind blowing perpendicular to arm!

Wind Moment = 287,000 in.-lb (see sht. 13)

Arm must rotate 73° in 7.6 sec. to be in fully retracted position when the blast goes by.

Assuming the arm accelerates for 3.8 sec. and decelerates the other 3.8 sec. and that it accelerates thru 36.5° and decelerates thru 36.5°

∴ From sheet 14 – T = Torque req'd = $287{,}000 + 4{,}140{,}000 \dfrac{\theta}{t^2}$

$\theta = .655$; $t = 3.8$ sec.

$$T = 287{,}000 + 4{,}140{,}000 \frac{(.655)}{(3.8)^2} = 287{,}000 + 188{,}000$$
$$= 475{,}000 \text{ in-lb.}$$

Torque calculations (Cont.)

Torque Req'd to Prevent Collision with Upper Skin

Wind Blowing Parallel to Arm!

$\theta = 6^\circ$; $t = 2.7$ sec

$\theta = .105$ Rad.; Allowing for .2 sec delay $t = 2.5$ sec.

Neglecting wind $T = 4{,}140{,}000 \frac{\theta}{t^2}$ see sht. 2

$T = 4{,}140{,}000 \frac{(.105)}{(2.5)^2} = 69{,}600$ in.-lb

Doubling torque as set forth @ top of Page 3A

$2T = 2(69{,}600) = 139{,}200$ in-lb

This is less than the torque req'd to move arm into Wind - ∴ Controlling Torque = 475,000 (See preceding page)

New time, $t = \sqrt{\frac{4{,}140{,}000(.105)}{475{,}000}} = .958$ sec.

Time F.S. $= \frac{2.5}{.958} = 2.61$

Torque Req'd to Prevent Collision with Fin

Wind Blowing Parallel to Arm!

$\theta = 52^\circ$, $t = 7.3$ sec.

$\theta = .907$ rad; Allowing for .2 sec delay, $t = 7.1$ sec

$T = 4{,}140{,}000 \frac{(.907)}{(7.1)^2} = 74{,}500$

Doubling Torque $2T = 2(74{,}500) = 149{,}000$ in.-lb

This is also less than torque req'd to move arm into wind.

∴ Controlling torque is still 475,000 in.-lb

New time, $t = \sqrt{\frac{4{,}140{,}000(.907)}{475{,}000}} = 2.81$ sec.

Time F.S. $= \frac{7.1}{2.81} = 2.53$

Assuming arm accelerates thru 36.5° and decelerates thru the next 36.5° and accelerates for 3.55 sec. and decelerates during the next 3.55 sec.

S-IV B Aft Umbilical Arm

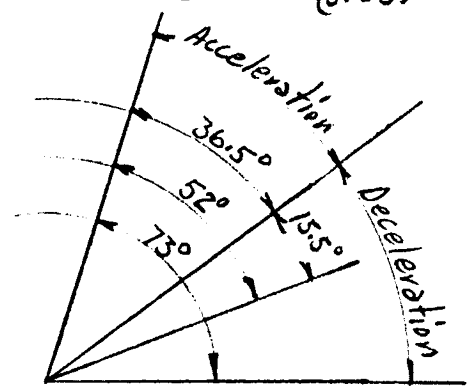
Torque Calculations (cont.)

Torque Req'd to Prevent Collision with Fin-cont.

Assuming constant angular acceleration and deceleration.

Acceleration thru 1st half of angle of rotation is 36.5° in 3.8 sec. (see sheet 15)

$$\alpha = \frac{2\theta}{t^2} = \frac{2(.655)}{(3.55)^2} = .104 \text{ rad/sec}^2$$ when wind is blowing against arm.



Time req'd to travel remaining 15.5° to clear the 52° collision angle.

$$t^2 = \frac{2\theta}{\alpha} = \frac{2(.27)}{.104} = 5.2 \text{ sec}^2$$

$$t = 2.28 \text{ sec.}$$

Total time to travel 52° = 3.8 + 2.28 = 6.08 sec. < 7.1 sec.

∴ OK

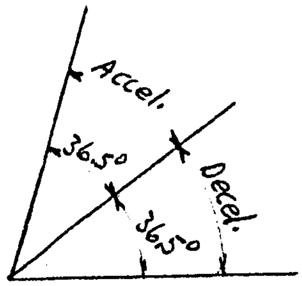
$$\text{Time F.S.} = \frac{7.1}{6.08} = 1.17$$

∴ 475,000 in-lb. of torque will move the arm through the req'd 52° in less than 7.1 sec. against the wind. With the wind from such a direction, there is no collision course with the vehicle. If wind were blowing in a collision course direction, arm would swing faster and Time F.S. would be greater.

S-IV B Aft Umbilical Arm

Deceleration Data

Assuming arm accelerates thru 36.5° and decelerates through 36.5° in 3.8 sec. and 3.8 sec. respectively.



When wind is not blowing against arm, its acceleration

$$\alpha = \frac{T}{I_m} = \frac{475{,}000}{2{,}070{,}000} = .229 \ \frac{rad}{sec^2}$$

$$\alpha_{accel.} = \alpha_{Decel.} = .229 \ rad/sec^2$$

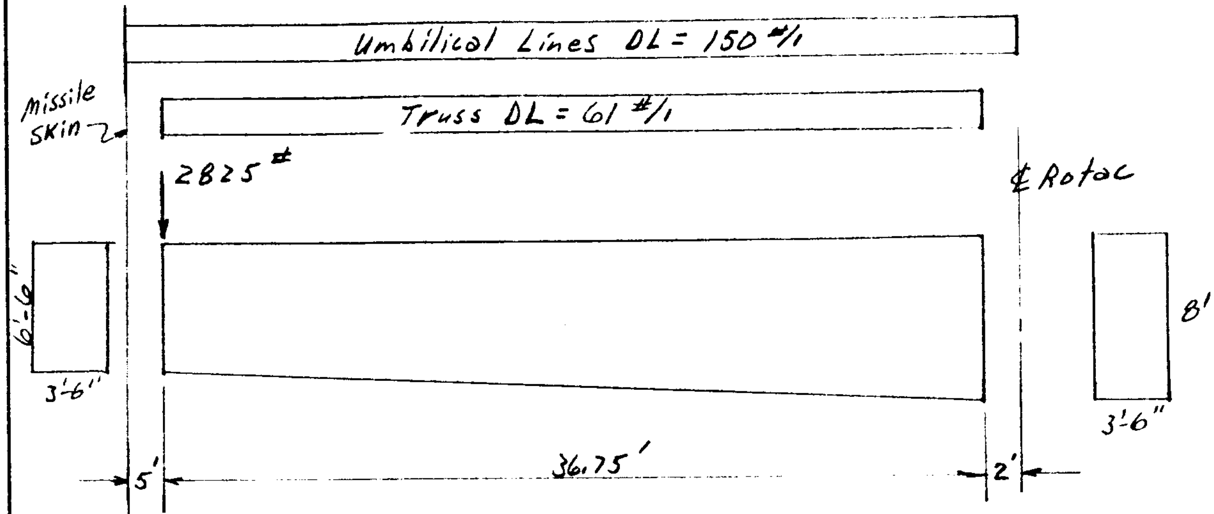
Torque req'd for Decel. with wind blowing in direction arm is rotating

$$T = \text{Wind Moment} + I_m \alpha$$

$$= 287{,}000 + 2{,}070{,}000(.229) =$$

$$= 287{,}000 + 474{,}000 = 761{,}000 \text{ in.-lb}$$

S II Aft Umbilical Arm



Retarding force of wind
@ 140' Level

Design wind velocity @ 100' = 41 Knots
" " " " 200' = 47 Knots
∴ @ 140' level wind vel. = 43.4 Knots
= 50 mph
= 73.4 ft/sec

$$q = \frac{\rho v^2}{2} = \frac{.002378(73.4)^2}{2} = 6.4 \text{ psf}$$

$$P = qA = 6.4\left(\frac{6.5+8}{2}\right)(36.75) = 1700^{\#}$$

Assume wind acts halfway out arm or $2 + \frac{36.75}{2} = 20.4'$

M @ ℄ Rotac = 1700(20.4) = 34,800 ft-lb = 418,000 in-lb

Assume 60% flute effect = 250,000 in.-lb.

$2825(38.75)^2$

Truss Loading

Umbilical Lines and 2825 conc. Load @ end of arm -

$$I_{m_{Hinge}} = 150^2(39.75)\left(\frac{39.75}{2}\right)^2 + 4(150)(39.75)^2 + 2825(38.75)^2$$

$$= 2,355,280 + 948,038 + 4,241,914 = 7,545,232$$

$$I_M = \frac{I_m}{g} = \frac{7,545,232}{32.2} = 234,324 \text{ lb-ft-sec}^2$$

Truss Dead Load -

$$I_{m_{Hinge}} = 61(36.75)(\overset{416}{20.4})^2 = 932,000$$

$$I_M = \frac{I_m}{g} = \frac{932,000}{32.2} = 29,000 \text{ lb-ft-sec}^2$$

$$\Sigma I_M = 234,324 + 29,000 = 263,324 \text{ lb-ft-sec}^2 = 3,160,000 \text{ lb.-in.-sec}^2$$

Torque Calculations

Wind moment = 250,000 in.-lb

Torque must overcome this plus inertial effect

$$T_{inertia} = \frac{I_M 2\theta}{t^2} = 3,160,000(2)\left(\frac{\theta}{t^2}\right) = 6,320,000\frac{\theta}{t^2}$$

Collision Course (fin) — $\theta = 24°$, $t = 5.7$ sec.
$\theta = .418$ rad

Allowing for .2 sec. delay and a S.F. of 2

$$t = \frac{5.7 - .2}{2} = \frac{5.5}{2} = 2.75 \text{ sec.}$$

$$T = 250,000 + 6,320,000\frac{(.418)}{\underset{7.56}{(2.75)^2}} = 250,000 + 348,000$$

$$= \underline{598,000 \text{ in. lb}}^*$$

*However, see sheets 22-23 for more realistic method of calculating torque.

S-II Aft Umbilical Arm

Torque Calculations (cont.)

Torque req'd to move Arm into Launch Wind
Wind blowing Perpendicular to arm!
Wind moment = 250,000 in-lb (see sht. 19)

Time before blast reaches arm position = 6 sec.
∴ Arm must be fully retracted in 6 sec.

Assume arm accelerates for 3 sec and decelerates for the other 3 sec. or it accelerates thru 36.5° and decelerates thru 36.5°.

T = Torque req'd $= 250{,}000 + 6{,}320{,}000 \frac{\theta}{t^2}$ (see sht. 20)

$\theta = .655$ rad. ; $t = 3$ sec.

$T = 250{,}000 + 6{,}320{,}000 \left(\frac{.655}{3^2}\right) = 250{,}000 + 460{,}000 = 710{,}000$ in-lb

Torque Calculations (cont.)

See sht. 15 for note stating change in method of calculating torque required.

Torque req'd to prevent collision with skin

$\theta = 6^0$; $t = 4.2$ sec; Wind parallel to arm

$\theta = .105$ rad.; Allowing for .2 sec delay $t = 4.0$ sec.

From sheet 20 — Neglecting wind $T = 6{,}320{,}000 \frac{\theta}{t^2}$

$$T = 6{,}320{,}000 \frac{(.105)}{(4)^2} = 41{,}500 \text{ in.-lb}$$

$$2T = 2(41{,}500) = \underline{83{,}000 \text{ in.lb}} < 710{,}000 \text{ in-lb}$$

Solving for corresponding t with 710,000 constant torque.

$$t^2 = \frac{6{,}320{,}000(\theta)}{T} = \frac{6{,}320{,}000(.105)}{710{,}000} = .936 \text{ sec.}^2$$

$t = .97$

$$\text{Time F.S.} = \frac{4.0}{.97} = 4.12$$

Torque req'd to prevent collision with fin

$\theta = 24^\circ$; $t = 5.9$ sec.; Wind parallel to arm

$\theta = .418$ rad; Allowing for .2 sec. delay $t = 5.7$ sec

$$T = 6{,}320{,}000 \frac{(.418)}{(5.7)^2} = 81{,}500 \text{ in.-lb}$$

$$2T = 2(81{,}500) = \underline{163{,}000 \text{ in.-lb}} < 710{,}000 \text{ in.-lb}$$

Solving for corresponding t with constant 710,000 torque

$$t^2 = \frac{6{,}320{,}000(.418)}{710{,}000} = 3.72 \text{ sec}^2$$

$t = 1.93$ sec

$$\text{Time F.S.} = \frac{5.9}{1.93} = 3.05$$

Torque Calculations-(Cont.)

Deceleration Data

Arm is assumed to accelerate thru 36.5° in 3.0 sec and to decelerate thru 36.5° in 3.0 sec.

Torque acting on arm during acceleration period = 710,000 in.-lb (see sht. 21).

I_m = 3,160,000 lb-in-sec^2 (see sht. 20)

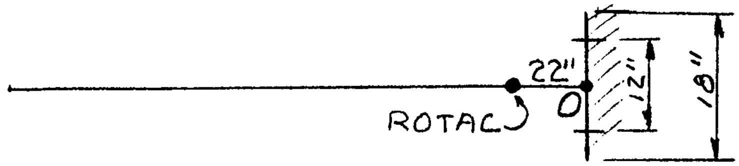
$$\therefore \alpha = \frac{T}{I_m} = \frac{710{,}000}{3{,}160{,}000} = .225 \text{ rad/sec}^2$$

$\therefore$ Total torque to decelerate when wind is blowing perpendicular to arm = Wind moment + $I_m\alpha$

$$= 250{,}000 + 3{,}160{,}000(.225) = 250{,}000 + 710{,}000 = 960{,}000 \text{ in-lb}$$

INVESTIGATE HIGH STRENGTH BOLTS TO UMBILICAL ARM TO TOWER COLUMN.

SEE PAGE 2 FOR LOADING



ASSUME 2 ROWS OF BOLTS 12" APART FOR CONVENIENCE OF SUPPORT COLUMN SECTION

$\Sigma M @ O$

200(534) = 106,800
1200(466) = 559,000
30 (566) = 16,980
227 (500) = 113,500
2040 (262) = 534,000
1752 (326) = 572,000

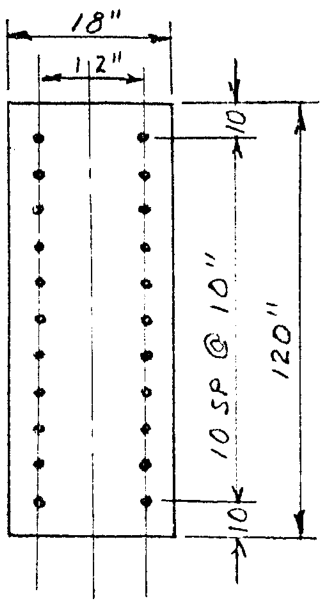
1,902,280 IN-LBS.

LOAD FACTOR OF 2, DEAD LOAD M = 3,804,560 IN. LBS.

480(594) = 285,000 IN.-LBS.

LOAD FACTOR OF 6, LIVE LOAD M = 1,710,000 IN-LBS

RESULTANT M = 5,514,560 IN.-LBS.

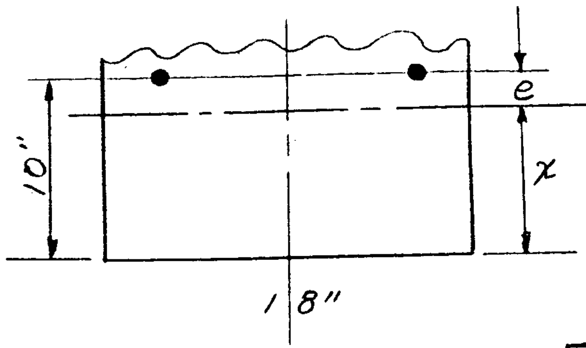


TRY 2 ROWS OF 3/4" BOLTS @ 10" SPACING

BASE ℄ TO BE 120" LONG TO ACCEPT TRUSS HINGE

$$n = \sqrt{\frac{6(5,515)}{10(17.64)(2)}} \times \frac{10}{11} = 9.85$$

SAY 10



11 - ¾"ϕ BOLTS $A = 0.4418 \text{ IN}^2$

$R = 17.67$ K/BOLT

$$\frac{18}{2} x^2 = 2(0.4418)\left[10 \frac{9}{2}(10) + 10(10-x)\right]$$

$$9x^2 = .8836\left[550 - 10x\right]$$

$$9x^2 + 8.84x - 486 = 0$$

$$x = \frac{-8.84 \pm \sqrt{78 - 4(9)(-486)}}{2(9)} = 6.87 \text{ IN.}$$

$$e = 10 - 6.87 = 3.13 \text{ IN.}$$

$$I = 2(0.4418)\left[10^2 \frac{9}{6}(10)(21) + 2(3.13)\left(\frac{9}{2}\right)(10)(10) + 10(3.13)^2\right]$$

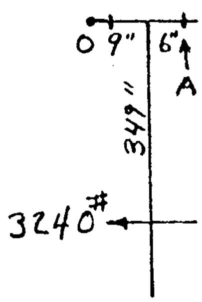
$$= .8836(34{,}116) = 30{,}100 \text{ IN.}^4$$

$$+ \frac{bd^3}{3} = \frac{18(6.87)^3}{3} = 1{,}940$$

$$\text{TOT. } I = 32{,}040 \text{ IN.}^4$$

$$R = \frac{5514(93.13)(0.4418)}{32{,}040} = 7.1 \text{ K/BOLT}$$

PLUS FORCE CAUSED BY ROTATION

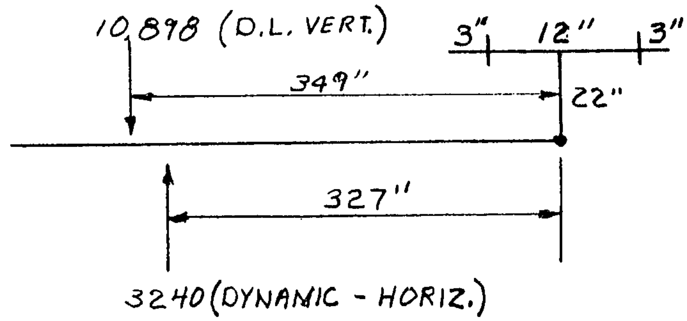


$$\text{FORCE A} = \frac{3240(349)}{15(11)} = 6.85 \text{ K/BOLT}$$

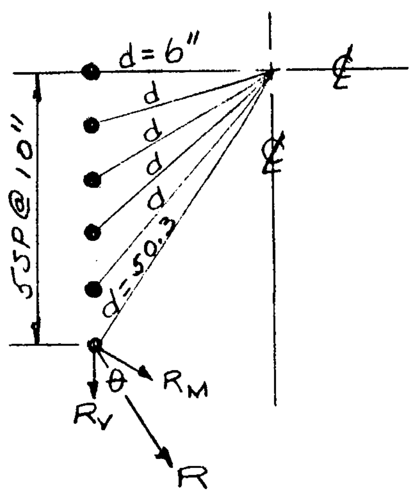
$$\text{TOT.} = 13.95 \text{ K/BOLT}$$

$$< 17.67 \therefore \text{O.K.}$$

CONSIDER ARM IN CLOSED POSITION



BOLT PATTERN RESISTS D.L. MOMENT BY SHEAR



$$\Sigma d^2 = 100\tfrac{5}{6}(6)(13) = 6500$$
$$+36(5) = 180$$
$$6,680$$
$$\times 4$$
$$26,720$$
$$+72$$
$$\Sigma d^2 = 26,792$$

$$R_M = \frac{Md}{\Sigma d^2} = \frac{10.898(349)(50.3)}{26,792} = 7.14^K$$

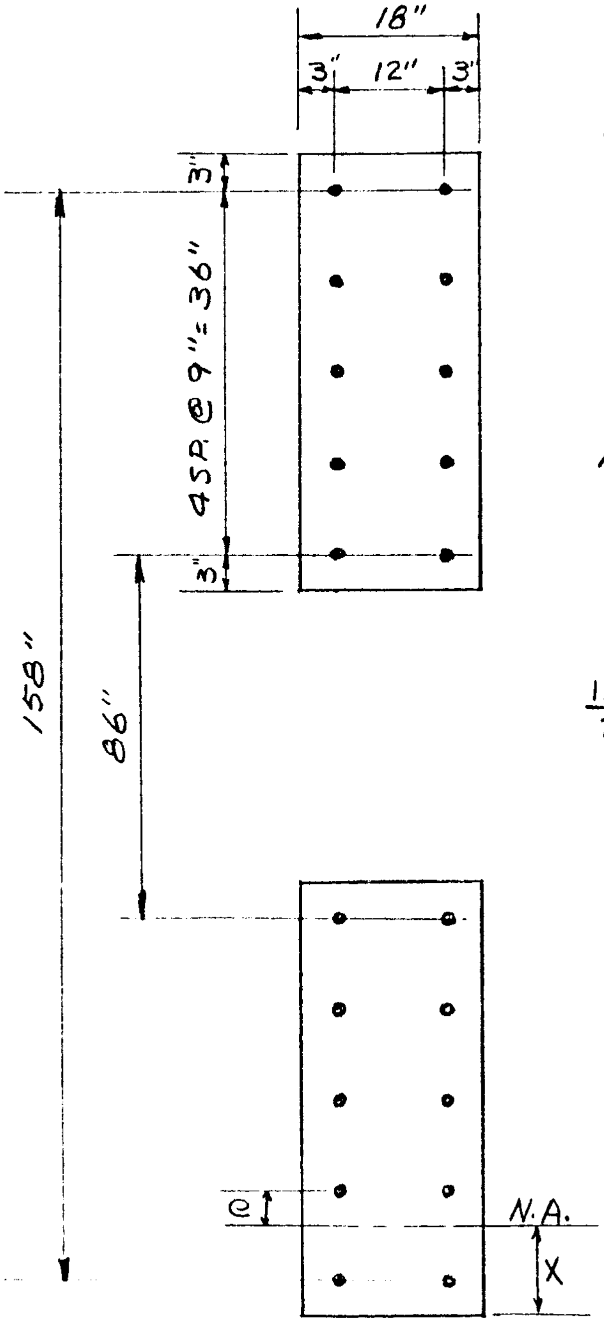
$$R_V : \frac{P}{n} = \frac{10,898}{22} = 0.495^K$$

$$R^2 = R_M^2 + R_V^2 + 2R_M R_V \cos\theta$$
$$= 7.14^2 + 0.49^2 + 2(7.14)(0.49)\left(\frac{6}{50.3}\right)$$
$$= 52.08\ K^2$$
$$R = 7.23\ ^K/\text{BOLT} \angle 17.67 \therefore OK$$

CHECK BOLTS AT BASE PL FOR 2 PAN CAKE UNITS.

USE 2 EQUAL SIZE BASE PLs.

SEE DWG. No. ______________.



CHECK FOR USE OF $\frac{3}{4}$"ϕ HIGH STRENGTH BOLTS

$A = 0.4418$ SQ. IN. $\quad R_T = 17.64$ K/BOLT

$M = 5{,}514{,}560$ IN-LBS.
(SEE APPENDIX PAGE 24)

No OF BOLTS

$$n = \sqrt{\frac{6(5.515)}{9(17.64)2} \times \frac{9}{10}} = 9.68$$

SAY 10/ROW

FIND NEUTRAL AXIS

$$\frac{18x^2}{2} - 2(0.4418)(x-3) =$$
$$= 2(0.4418)\left[9\left(\frac{3}{2}\right)4 + 4(12-x) + 9\left(\frac{4}{2}\right)5 + 5(125-x)\right.$$

$$9x^2 + 7.07x - 719.35 = 0$$

$X = 8.55$ IN.

$e = 3.45$ IN.

$$I = 2(0.4418)\Big[9^2\left(\tfrac{3}{6}\right)4(7) + 9^2\left(\tfrac{4}{6}\right)5(9) + 2(3.45)\tfrac{3}{2}(4)9$$
$$+ 2(116.45)\left(\tfrac{4}{2}\right)5(9) + 4(3.45)^2 + 5(116.45)^2\Big]$$

$$= 75{,}600 \text{ IN}^4$$

$$+\frac{bd^3}{3} = \frac{18(8.55)^2}{3} = 3{,}730$$

$$79{,}330 \text{ IN}^4$$

$$-2(0.5185)(5.55)^2 \qquad 30$$

$$I = 79{,}300 \text{ IN}^4$$

$$R: \frac{5{,}515(152.45)(0.4418)}{79{,}300} = 4.68 \text{ }^K/\text{BOLT}$$

PLUS TENSION DUE TO ROTATION = $7.55\ ^K/\text{BOLT}$

$$17.64^K > 12.23\ ^K/\text{BOLT} \therefore \text{O.K.}$$

COST ESTIMATE

FOR BASIC ARM ASSEMBLY OF C-5 VEHICLE

BILL OF MATERIAL

DISCRIPTION	PRICE	QUANTITY	AMOUNT
TUBING:-			
AL. ALLOY, 6061-T6, 3"φ x 7/16" WALL	0.803 $/lb.	1011 lbs.	$813.00
AL. ALLOY, 6061-T6 2½"φ x 3/16" WALL	1.25 $/lb.	382 lbs	493.00
AL. ALLOY, 6061-T6 1¼"φ x 1/8" WALL	1.00 $/lb.	33 lbs.	33.00
HARDWARE; NUTS, BOLTS, RIVETS, ETC.			60.00
RAW MATERIAL:-			
ALMAG 35	0.375 $/lb.	150 lbs.	57.00
AL. ∠s 6x3x5/16 (6061-T6)	0.803 $/lb.	403 lbs	324.00
EXPANDED METAL FLOORING	2.00 $/SQ.FT.	136 SQ.FT.	272.00
UNISTRUT	0.75 $/FT.	125 FT.	94.00
WIRE CLOTH	2.50 $/SQ.FT	544 SQ.FT.	1360.00
		TOTAL	$3506.00

EXTENSION TO BASIC ARM

AL. ALLOY. 6061-T6 2½"φ x 3/16 WALL	1.25 $/lb	129 lb.	$161.00
ALMAG 35	0.375 $/lb.	16 lb.	6.00
EXPANDED METAL FLOORING	2.00 $/SQ.FT	23 SQ.FT	26.00
AL. ∠s 6x3x5/16 (6061-T6)	0.803 $/lb.	18 lb.	15.00
UNISTRUT	0.75 $/FT.	30 FT	23.00
WIRE CLOTH	2.50 $/SQ.FT.	84 SQ.FT	210.00
		TOTAL	$441.00

ESTIMATED LABOR COST
FOR BASIC ARM TRUSS

CATEGORY	MAN-HOURS	AVE. RATE	TOT. LAB. COST
MACHINE SHOP	300	5.85	1,755.00
FAB-WELD	275	6.00	1,650.00
PLATING & PAINTING	40	5.30	212.00
SHEET METAL	225	5.95	1,340.00
INSPECTION	80	1.90	392.00
QUALITY CONTROL	25	6.50	163.00
			$ 5512.00

MATERIAL COST	$ 3,506.00
LABOR COST	5,512.00
10% PROFIT	902.00
	$ 9,910.00

BROWN ENGINEERING COMPANY, INC.
P. O. BOX DRAWER 917
PHONE JE 6-5536
HUNTSVILLE, ALABAMA

ESTIMATED LABOR COST
FOR EXTENSION TO BASIC ARM TRUSS
OF C-5 VEHICLE

CATEGORY	MAN-HOURS	AVG. RATE	TOT. LAB. COST
MACHINE SHOP	50	5.85	292.00
FAB-WELD	45	6.00	270.00
PLATING & PAINTING	8	5.30	43.00
SHEET METAL	35	5.95	208.00
INSPECTION	14	4.90	68.00
QUALITY CONTROL	4	6.50	26.00
			907.00

MATERIAL COST	\$ 441.00
LABOR COST	907.00
10% PROFIT	135.00
	\$ 1,583.00

USE 1600.00

PREPARED BY SWH
CHECKED BY gJD
REVISED BY

BROWN ENGINEERING COMPANY, INC.
P. O. BOX DRAWER 917
PHONE JE 6-5536
HUNTSVILLE, ALABAMA

PAGE 32
REPORT NO.
DATE 10/20/62

COST ESTIMATE
FOR BACK PLATE AND ACTUATOR SUPPORT OF ACTUATING ASSEMBLY OF C-5 UMBILICAL ARM

BILL OF MATERIAL

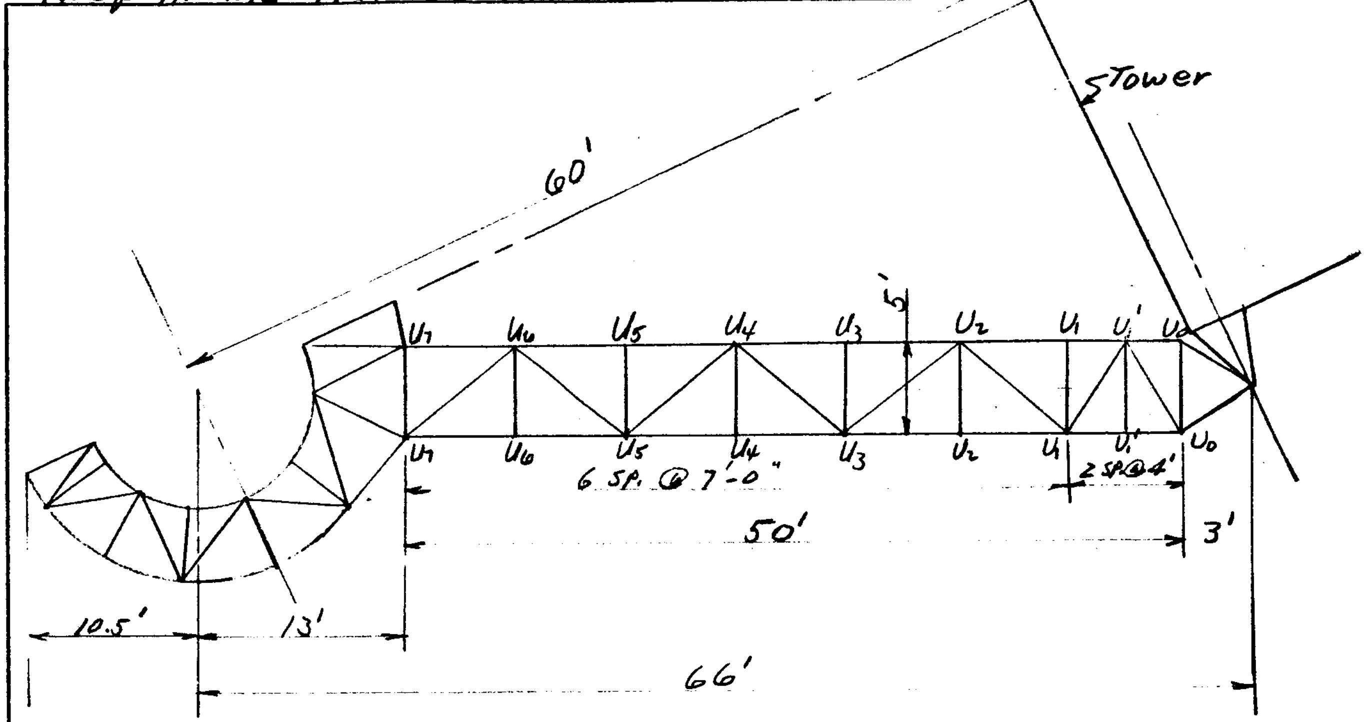
DISCRIPTION	PRICE	QUANTITY	AMOUNT
RAW MATERIAL			
STEEL 4130	0.403 $/lb.	2350 lb.	$ 945.00
ALMAG 35	0.375	2000	650.00
		TOTAL	$ 1,595.00

ESTIMATED LABOR COST

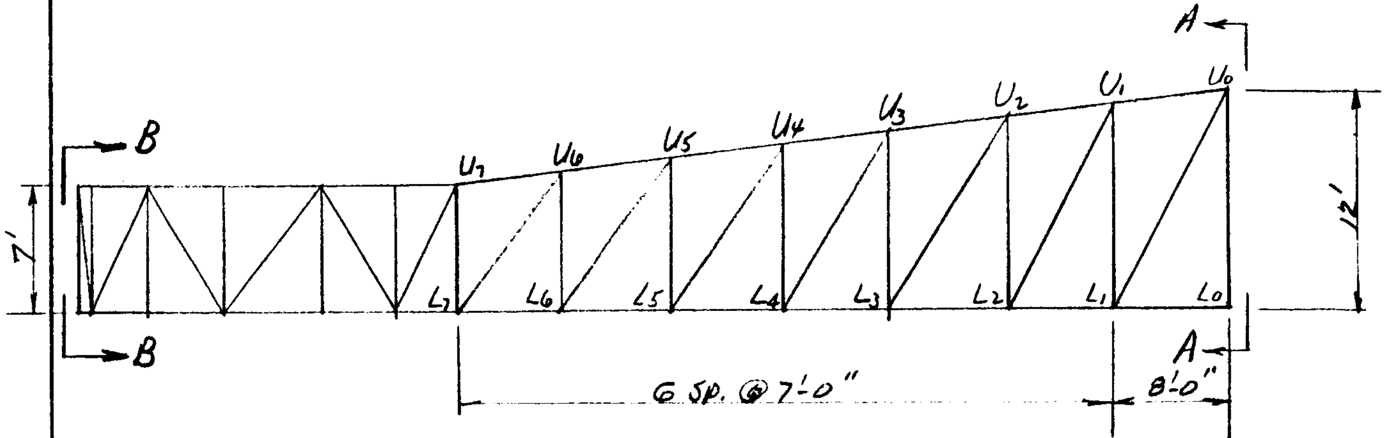
CATEGORY	MAN-HOURS	AVG. RATE	TOT. COST
MACHINE SHOP	300	5.85	1,755.00
FAB-WELD	80	6.00	480.00
PLATING & PAINTING	30	5.30	159.00
INSPECTION	40	4.90	196.00
QUALITY CONTROL	40	6.50	260.00
			2,850.00

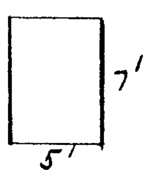
MATERIAL COST	$ 1,595.00
LABOR COST	2,850.00
PROFIT 10%	445.00
TOTAL	$ 4,890.00
Carry over page 30	9,910.00
	$ 14,800.00

Wrap-Around Access Arms

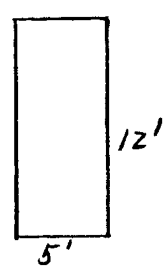


Note: All dimensions scaled from drawings!





Section B-B



Section A-A

Wrap-Around Access Arms

Load Factors —

LL – 6
DL – 2
WL – 2

Loadings —

LL – Consider as 9 men weighing 250# each
$9(250) = 2250$#

DL – (Assumed)

Main Members – 5"ϕ with $\frac{1}{4}$" walls @ 5#/'
$4 \times 5 =$ – – – 20#/'

Diagonals – $2\frac{1}{2}$"ϕ with $\frac{1}{4}$" walls @ 3#/'
(Avg.) $\frac{2(12)(3)+2(9)(3)}{7} =$ – – – – – 18#/'

Verticals + horizontals – $2\frac{1}{2}$"ϕ with $\frac{1}{4}$" walls @ 3#/'
(Avg.) $\frac{(9+9+5+5)3}{7} = \frac{84}{7} =$ – 12#/'

Handrail – $1\frac{1}{2}$"ϕ with $\frac{1}{8}$" walls @ .7#/'
$2(.7) =$ – – – – – – – 2#/'

Flooring – 2#/□'
$2(5) = 10$#/' – – – 10#/'

Floor support – 3x2 ∟s @ 2#/'
say 4#/' w/crossmembers = 8#/'

Mesh – 1#/□' Est. Avg. height = 9'
$2(9) = 18$#/' – – – – – 18#/'

Umbilical Lines – Est. @ 15#/' – – 15#/'
103#/'

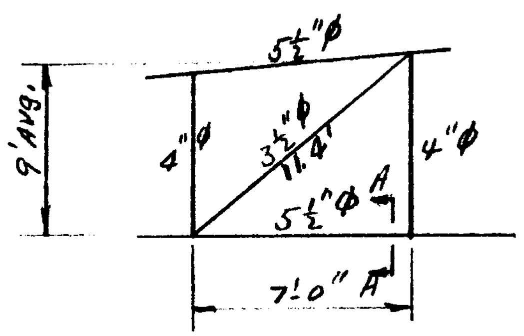
say 110#/'

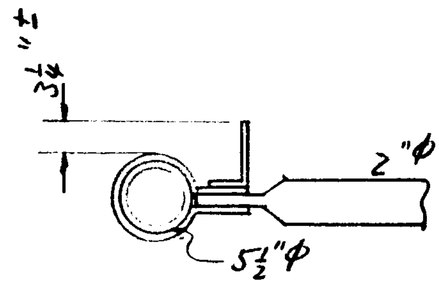
Work Platform –
Est. wt = 350# – – – 350#

Wrap-Around Access Arms

Solidity Ratio

Isolating an average panel of the platform



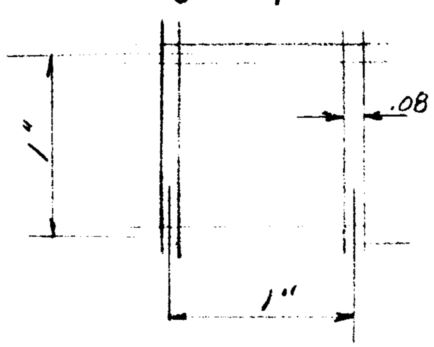


Total Area of panel = $7(9)(144) = 9080\,\square''$

$5\tfrac{1}{2}''\phi$ – $11''(84) = 923\,\square''$
$3\tfrac{1}{2}''\phi$ – $3.5(137) = 478\,\square''$
$4''\phi$ – $4(108) = 432\,\square''$
L – $3.25(84) = 273\,\square''$
$\ 2106$

Ratio for members $= \dfrac{2106}{9080} = .232$ or 23.2 %

Isolating 1" square of the 1" mesh



Area of wire $= \dfrac{.08}{2}(4)(1) = .16\,\square''$

Ratio $= \dfrac{.16}{1} = .16$ or 16 %

∴ Solidity Ratio = 23.2 + 16 = 39.2 % say 40 %

This is conservative since it does not take into account the fact that the truss members will, no doubt be tubes.

Wrap-Around Access Arms

Loadings (cont.)

WL –

Use solidity ratio = .40 = ϕ

Max. Wind – @ 350'$^{\pm}$ Level = 66 Knots

= 66(1.152) = 76 MPH

$q = .002558 V^2 (1.8\phi)$

$= .002558(76)^2(1.8)(.4) = 10.6$ #/□'

Say 11 #/□'

Launch Wind – @ 350'$^{\pm}$ level = 62.3 mph

$q = .02558(62.3)^2(1.8)(.4) = 7.2$ #/□'

Say 8 #/□'

Design Conditions

Case I –

DL + LL + Launch wind with LL @ End of arm and neglecting any eccentricity.

Case II –

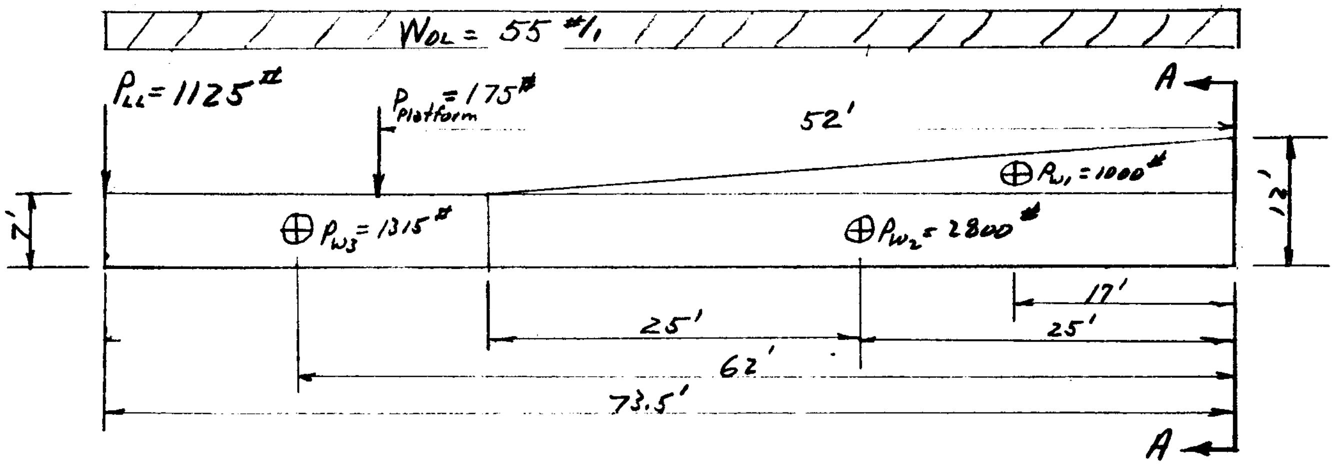
DL + LL + Launch Wind with LL @ point of maximum eccentricity and considering both DL and LL ecc.

Case III

DL + max. wind and neglecting any eccentricity

Wrap-Around Access Arms

Case I (DL + LL + Launch wind w/no eccentricity considered)
Neglecting any DL or LL torsion!



Loads for one truss —

$W_{DL} = \frac{110}{2} = 55$ #/,

$P_{platform} = \frac{350}{2} = 175$ #

$P_{LL} = \frac{2250}{2} = 1125$ #

$P_{w_1} = \frac{1}{2}(5)(50)(8) = 1000$ #

$P_{w_2} = 50(7)(8) = 2800$ #

$P_{w_3} = 23.5(7)(8) = 1315$ #

Load in Lower chord @ section A-A

W_{DL} —

$M_{DL} = 55(73.5)(\frac{73.5}{2}) = 149{,}000$ ft-lb

$F_{DL} = \frac{149{,}000}{12} = 12{,}400$ #

F_{DL} with F.S. of 2 = 24,800 #

$P_{platform}$

$M = 175(52) = 9100$ ft-lb.

$F_{plat.} = \frac{9100}{12} = 757$ #

$F_{plat.}$ with F.S. of 2 = 1514 #

P_{LL} —

$M_{LL} = 1125(73.5) = 82{,}700$ ft-lb

$F_{LL} = \frac{82{,}700}{12} = 6900$ #

F_{LL} with F.S. of 6 = 41,400 #

Case I (cont.)

Load in Lower Chord @ Section A-A (cont.)

P_w —

$M_w = 1000(17) + 2800(25) + 1315(62) = 17{,}000 + 70{,}000 + 81{,}600$
$= 168{,}600$ ft-lb

$F_W = \frac{168{,}600}{5} = 33{,}700^{\#}$

F_W with F.S. of 2 = $\underline{67{,}400}^{\#}$

Σ Loads $= 24{,}800 + 1514 + 41{,}400 + 67{,}400 = 135{,}114$ Comp.

Column Check – Assuming 7075-T6

Checking assumed 5"ϕ tube with ¼" walls

$L = 8' = 96''$; $r = 1.682$; $K = 1$; $A = 3.73\,\square''$

$\frac{KL}{r} = \frac{96}{1.682} = 57$

$f_c = \frac{102{,}000}{(KL/r)^2} = \frac{102{,}000}{(57)^2} = 31.5$ Ksi

P col. will carry $= 3.73(31.5) = 118{,}000^{\#} < 135{,}114^{\#}$ ∴ No Good

Try 5½"ϕ tube with ¼" walls

$r = 1.858$; $A = 4.123\,\square''$

$\frac{KL}{r} = \frac{96}{1.858} = 51.7$

$f_c = \frac{102{,}000}{(51.7)^2} = 38.2$ Ksi

P col. will carry $= 4.123(38.2) = 157{,}500^{\#} > 135{,}144$ ∴ O.K.

Increase in weight does not cause an excess over that assumed (assumed = 5 #/' ; Actual = 4.8 #/')

Use 5½"ϕ Tube with ¼" walls

Case II (DL+LL+Launch wind with eccentricity considered)

All loads for this condition are the same as for Case I except LL. LL will be placed @ pt. of max. eccentricity which is 62.5' from big end of truss. Max. eccentricity = 9'.

It is obvious case I is more critical than case II so far as sizing the top and bottom chords. However, the torsion caused by the eccentricity of the LL in Case II will effect the size of the truss verticals and diagonals.

There is also some DL eccentricity which will be considered under this case. Avg. e will be assumed as 5' and an ecc. DL of 23.5(55) = 1295# will be used

Max. torsion = 1125(9)(6) + 1295(5)(2) = 60,750 + 12950
= 73,700 ft-lb

see Fig. on P. 4

Max. vert. shear @ section A-A –

1125(6) = – – – – –	= 6750
55(73.5)(2) – – –	= 8080
175(2) – – – – –	= 350
	15,180#

Max. Hor. shear @ Section A-A –

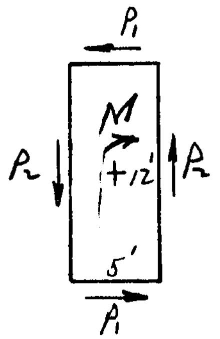
$V_h = 1000 + 2800 + 1315 = 5115^{\#}$

V_h with F.S. of 2 = 10,230#

Wrap-Around Access Arms

Case II (cont.)

The torsion will be taken by couples made up of forces in the diagonals; both the diagonals in the vertical plane and those in the horizontal plane. Magnitudes of the couples will be proportional to the distance of the diagonals from the center of the trussed frame.



Couple P_1 will be $\frac{12}{5}$ times as large as couple P_2

$M = 73{,}700$ ft.-lb

$\frac{12}{5}(M_2) + M_2 = 73{,}700$

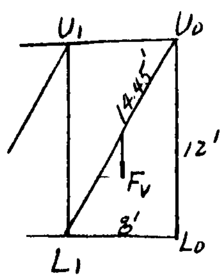
$3.4 M_2 = 73{,}700$

$M_2 = 21{,}700$ ft-lb

$M_1 = 2.4(21{,}700) = 52{,}000$ ft-lb

$P_1 = \frac{52{,}000}{12} = 4340^{\#}$

$P_2 = \frac{21{,}700}{5} = 4340^{\#}$



Member U_0L_1

$F_V = 15{,}180 \pm 4340^{\#}$

$F_V\ max. = 19{,}520^{\#}$

$F_{U_0L_1} = 19{,}250\left(\frac{14.45}{12}\right) = 23{,}200^{\#}$ tension

Check assumed $2\frac{1}{2}''\phi$ Tube with $\frac{1}{4}''$ wall

$P = f_{ty}A$ Assuming 7075-T6 $f_{ty} = 72{,}000$ psi

$P = 72{,}000(1.767) = 127{,}000^{\#} > 23{,}200^{\#}$ too conservative

But limiting $L/r = 150$

$\frac{14.45(12)}{r} = 150 = \frac{173.5}{r}$; $r = \frac{173.5}{150} = 1.155$

Use $3\frac{1}{2}''\phi$ Tube with $\frac{1}{4}''$ walls

Assumed wt. $= 3^{\#/\prime}$

Actual wt. $= 3.002^{\#/\prime}$

Wrap-Around Access Arms

Case II (Cont.)

Member U_oL_o

$F_{U_oL_o} = 19{,}520^{\#}$ Compression

Check Assumed $2\frac{1}{2}''\phi$ tube with $\frac{1}{4}''$ walls

$r = .8$; $L = 144''$; $K = 1$; $\frac{KL}{r} = \frac{144}{.8} = 180$

$F_c = 3.1$ KSI (P.113 of Alcoa Hdbk.)

This is obviously too low

Try $4''\phi$ Tube with $\frac{1}{4}''$ walls

$r = 1.329$; $\frac{KL}{r} = \frac{144}{1.329} = 108.5$

$$F_c = \frac{102{,}000}{(KL/R)^2} = \frac{102{,}000}{(108.5)^2} = \frac{102{,}000}{11{,}800} = 8.64 \text{ KSI}$$

$P = F_c A$ $\quad A = 2.945$

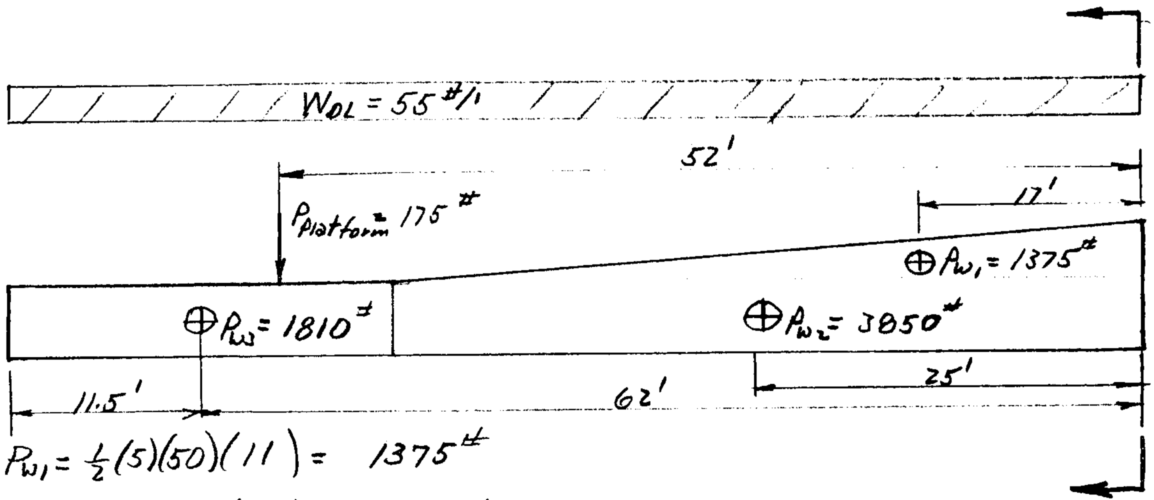
$P = 8.64(2.945) = 25{,}500^{\#} > 19{,}520^{\#} \therefore OK$

Use $4''\phi$ Tube with $\frac{1}{4}''$ walls

Assumed wt. $= 3^{\#/'}$
Actual wt. $= 3.463^{\#/'}$

Wrap-Around Access Arms

Case III (DL + Max. Wind)



$P_{w_1} = \frac{1}{2}(5)(50)(11) = 1375^{\#}$

$P_{w_2} = 50(7)(11) = 3850^{\#}$

$P_{w_3} = 23.5(7)(11) = 1810^{\#}$

Load in Lower Chord @ Section A-A

W_{DL} —

F_{DL} with F.S. of 2 = 24,800# (see sht. 4)

$P_{platform}$ —

$F_{plat.}$ with F.S. of 2 = 1514# (see sht. 4)

P_w —

$M_w = 1375(17) + 3850(25) + 1810(62)$

$= 23,400 + 96,300 + 112,200 = 231,900$ ft-lb

$F_w = \frac{231,900}{5} = 46,400$

F_w with F.S. of 2 = 92,800#

Σ Forces In lower chord = 24,800 + 1514 + 92,800 = 119,114#

This is less than the 135,114# for case I

∴ Case I Controls Chord Design

Max. Hor. Shear

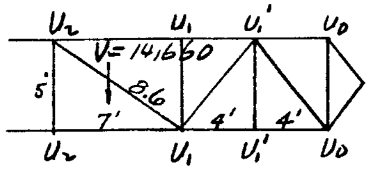
$V_h = 1375 + 3850 + 1810 = 7,035^{\#}$

V_h with F.S. of 2 = 14,070#

Horizontal Diagonals

Max. Hor. shear occurs under case II when the shear due to wind and the shear due to torsion are additive.

From P.6 $V_h = 10{,}230^{\#}$; From P.7 torsional shear = 4,340



$V = 10{,}320 + 4340 = 14{,}660$

Assuming this shear occurs in member U_1U_2 such that the member is in compression

$F_{U_1U_2} = \frac{8.6}{5}(14{,}660) = 25{,}200^{\#}$ compression

Check of assumed $2\frac{1}{2}''\phi$ Tube with $\frac{1}{4}''$ walls

$A = 1.77^{\square''}$; $r = .8$ $L = 8.6' = 103.2''$; $K = 1$; $\frac{KL}{r} = \frac{103.2}{.8} = 129$

$F_c = \frac{102{,}000}{(129)^2} = 6.12$ KSI

$P = F_c A = 6.12(1.77) = 10.84^K < 25.2^K$ ∴ No. Good

Try $3\frac{1}{2}''\phi$ Tube with $\frac{1}{4}''$ walls

$r = 1.153$; $A = 2.553$; $\frac{KL}{r} = \frac{103.2}{1.153} = 89.5$

$F_c = \frac{102{,}000}{(89.5)^2} = 12.75$ KSI

$P = F_c A = 12.75(2.553) = 32.5 > 25.2$ KSI ∴ OK.

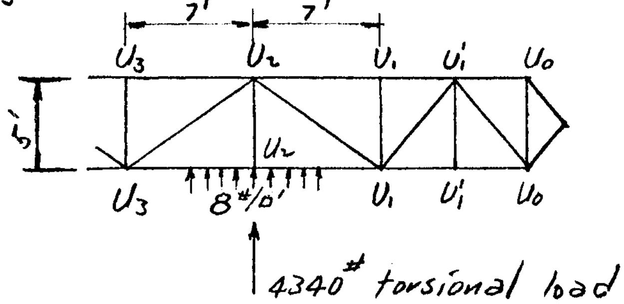
Use $3\frac{1}{2}''\phi$ Tube with $\frac{1}{4}''$ walls

Assumed wt. = $3^{\#/1}$

Actual wt. = $3.002^{\#/1}$

Horizontals —

Member U_2U_2 will be assumed to be the critical Horizontal. This member carries only the wind pressure on the area adjacent and it will be assumed to carry the max. torsional compression load.



Half depth of truss @ this point = 5.5'±

Wind Load = $7(5.5)(8)(2) = 616^{\#}$ (L.F.)

$F_{U_2U_2} = 616 + 4340 = 4956^{\#}$ Compression

Check of Assumed $2\frac{1}{2}''\phi$ Tube with $\frac{1}{4}''$ walls

$r = .8$; $L = 60''$; $K = 1$; $\frac{KL}{r} = \frac{60}{.8} = 75$

$F_c = 18.1$ KSI (P.113 Alcoa)

$P = F_cA$ $A = 1.767\square''$ $P = 18.1(1.767) = 32$ KSI > 4.956 KSI
Too conservative

Try $2''\phi$ Tube with $\frac{1}{4}''$ walls

$r = .625$ $\frac{KL}{r} = \frac{60}{.625} = 96$; $F_c = 11.1$ KSI (P.113 Alcoa)

$P = F_cA$; $A = 1.374$; $P = 11.1(1.374) = 15.2 > 4.956$ KSI

This is conservative but the umbilical lines will no doubt be hung from these members so the $2''\phi$ tube will be used. (Floor also will rest on these members.)

Use $2''\phi$ tube with $\frac{1}{4}''$ walls

Assumed wt = $3^{\#}/'$
Actual wt = $1.616^{\#}/'$

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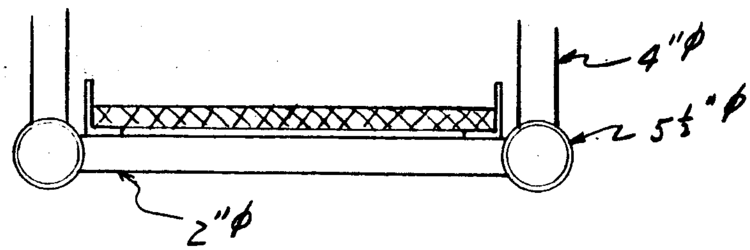
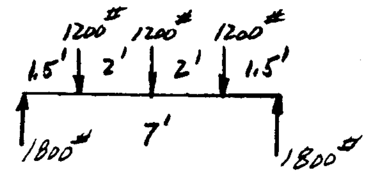
Wrap-Around Access Arms

Flooring Supports



Distance between truss panel points is a max. of 7'

Max. Loading for one angle supporting floor will be considered 3 men weighing 200# each and spaced 2' apart. Including LL Load Factor of 6, ea. man weighs 1200#.



$M_{max} = 1800(3.5) - 1200(2)$
$= 6300 - 2400 = 3900$ ft-lb
$= 46,800$ in.-lb

Assuming 7075-T6 $F_{ty} = 70,000$ psi ; $F_{cy} = 70,000$ psi

$f = \frac{Mc}{I} \quad \frac{I}{c} = \frac{M}{f} = \frac{M}{F} = \frac{46,800}{70,000} = .67 \text{ in.}^3$

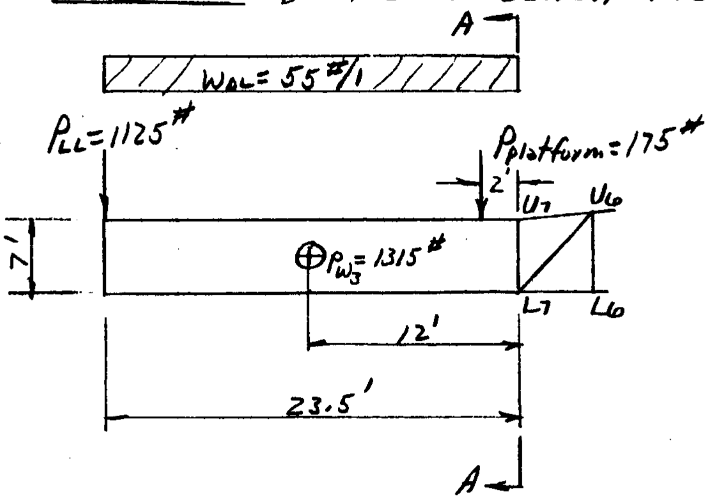
Try $6 \times 3\frac{1}{2} \times \frac{5}{16}$ ∠ $\quad \frac{I}{c} = .98 > .67$ OK

∴ use $4 \times 3\frac{1}{2} \times \frac{5}{16}$ ∠

Assumed wt = 4#/1
Actual wt. = 3.4#/1 (Assuming no cross-members)

Wrap-Around Access Arms

Case I DL + LL + Launch wind and Neglecting any torsion



see sht. 4 for calculation of Loads.

Load in Lower Chord @ Section A-A

$$F_{DL} = 55'(23.5')\left(\frac{23.5'}{2}\right)\left(\frac{1}{7}\right)(\underset{L.F.}{2}) = 4340^{\#}$$

$$F_{platform} = 175(2)\left(\frac{1}{7}\right)(2) = 100^{\#}$$

$$F_{LL} = 1125(23.5)\left(\frac{1}{7}\right)(6) = 23650^{\#}$$

$$F_{W} = 1315(12)\left(\frac{1}{5}\right)(2) = 6320^{\#}$$

$$\Sigma \text{ Forces} = 4340 + 100 + 23,650 + 6,320 = 33,410^{\#} \text{ compression}$$

Check of size of Lower Chord

$L = 7' = 84''$

Try $3\frac{1}{4}''\Phi$ Tube with $\frac{1}{4}''$ walls

$r = 1.064$; $K = 1$; $\frac{KL}{r} = \frac{84}{1.064} = 79$; $F_c = 16.3$ KSI (P.113 Alcoa)

$P = F_c A$; $A = 2.356$ $P = 16.3(2.356) = 38.4 \text{ KSI} > 33.41 \therefore$ OK

Use $3\frac{1}{4}''\Phi$ Tube with $\frac{1}{4}''$ walls

$\therefore$ Chord size can be reduced from $5\frac{1}{2}''\Phi$ to $3\frac{1}{4}''\Phi$ @ Junction of curved and Straight sections

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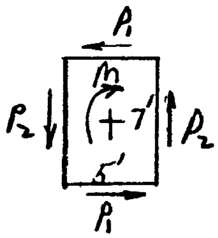
Wrap-Around Access Platforms

Case II DL+LL+Launch wind considering DL and LL torsion

Torsion

See sht. 6 for calculation of DL+LL torsion = 73,700 ft-lb

Assuming torsion taken as stated on sht. 7



$M = 73{,}700$ ft-lb

$\frac{7}{5} M_2 + M_2 = 73{,}700$

$2.4 M_2 = 73{,}700$

$M_2 = 30{,}700$ ft-lb

$M_1 = 1.4(30{,}700) = 43{,}000$ ft-lb

$P_1 = \frac{43{,}000}{7} = 6140^{\#}$

$P_2 = \frac{30{,}700}{5} = 6140^{\#}$

Max. Vertical shear (see sketch on sht. 13)

1125 (6) = - - - =	6750
55(23.5)(2) = - - =	2590
175 (2) = - - - =	350
	9,690 #

Max. Hor. shear

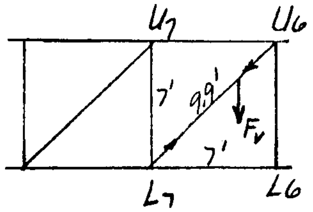
$1315(2) = 2630^{\#}$

Case III DL + Max. Wind

This Loading was found not to be critical when the section @ the big end of the truss was checked.

Wrap-Around Access Platforms

Diagonal U_6L_7



$F_V = 9690 \pm 6140$

F_V max. $= 15{,}830^{\#}$

$F_{U_6L_7} = \frac{9.9}{7}(15{,}830) = 22{,}400^{\#}$ Tension

Limiting $L/r = 150$; $L = 9.9' = 119''$

$\frac{L}{r} = 150 = \frac{119}{r}$; $r = \frac{119}{150} = .793$

Use $2\frac{1}{2}''\phi$ Tube with $\frac{1}{4}''$ walls

Vertical U_7L_7

$F_{U_7L_7} = 15{,}830$ compression

$L = 84''$

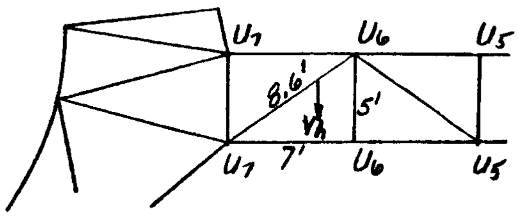
Try $2\frac{1}{2}''\phi$ with $\frac{1}{4}''$ walls

$r = .8$; $K = 1$; $\frac{KL}{r} = \frac{84}{.8} = 105$; $F_c = 9.2$ (p.113 Alcoa)

$P = F_cA$; $A = 1.767$; $P = 9.2(1.767) = 16.25$ KSI > 15.83 KSI $\therefore$ OK

Use $2\frac{1}{2}''\phi$ Tube with $\frac{1}{4}''$ walls

Horizontal Members



Diagonal U_6U_7

Max. Hor. shear occurs as stated @ top of sht. 10.

V_h max = 2630 + 6140 = 8770#

$F_{U_6U_7} = \frac{8.6}{5}(8770) = 15{,}100$# Assumed Compression

Try 3"φ with ¼" walls

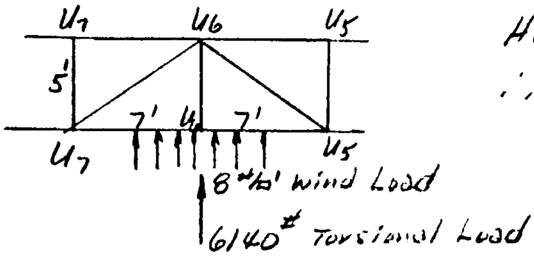
$r = .976$; $L = 8.6' = 103.2"$; $K=1$; $\frac{KL}{r} = \frac{103.2}{.976} = 106$

$F_c = 9.1$ KSI (P. 113 Alcoa)

$A = 2.16^{\square"}$; $P = F_cA = 9.1(2.16) = 19.7$ KSI > 15.1 KSI ∴ OK

Use 3"φ Tube with ¼" walls

Horizontal U_6L_6



Half depth of truss = 3.5' L.F.

∴ Wind Load = 7'(3.5')(8)(2) = 392

$F_{U_6U_6} = 392 + 6140 = 6532$# comp.

Try 2"φ with ¼" walls

$r = .625$; $L = 60"$; $K = 1$; $\frac{KL}{r} = \frac{60}{.625} = 96$; $F_c = 11.1$ KSI (P. 113 Alcoa)

$A = 1.374$ $P = F_cA = 11.1(1.374) = 15.2 > 6.532$ KSI ∴ OK

This is conservative but the floor system will be supported by these members in the Lower plane and the umbilical Lines in the upper plane.

∴ Use 2"φ Tube with ¼" walls

Adjusted Deadload

Deadload for the first 50' from the big end of the truss structure remains the same as originally assumed or 110 #/'. From this 50' point to the end of the arm the DL has been reduced as shown below.

Main members – $3\frac{1}{2}''\phi$ with $\frac{1}{4}''$ walls @ 4 #/'

4×4 = — — — — — 16 #/'

Diagonals – In Vert. Plane $2\frac{1}{2}''\phi \times \frac{1}{4}''$ walls @ 3 #/'
In Hor. Plane $3''\phi \times \frac{1}{4}''$ wall @ 3 #/'

$\frac{2 \times 9.0 \times 3 + 2 \times 5.5 \times 3}{5}$ = — — — — 18 #/'

Verticals and Horizontals –
In Vert. Plane $2\frac{1}{2}''\phi \times \frac{1}{4}''$ walls @ 3 #/'
In Hor. Plane $2''\phi \times \frac{1}{4}''$ walls @ 2 #/'

$\frac{2 \times 5 \times 3 + 2 \times 5 \times 2}{5'}$ = — — — — — 10 #/'

44 #/'

Originally assumed weights for these members
= 20 + 18 + 12 — — — = 50 #/'

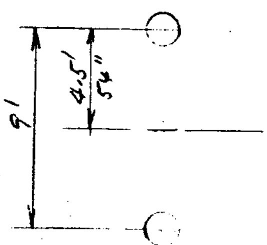
Since the effect of the curvature is not reflected in the above reduced figures, the originally assumed weights are probably the more realistic. ∴ use 110 #/' uniform load for full length of arm.

Wrap-Around Access Arms

Deflection

Case I presents the critical loading for deflection. The truss will be assumed to act as a beam with a "I" equal to the "I" of the top and bottom chord and with an average depth of 9'

Area of $5\frac{1}{2}"\phi \times \frac{1}{4}"$ wall tube = $4.123 \square"$



$$I = Ay^2 = 2(4.123)(54)^2 = 24{,}000 \text{ in.}^4$$

2916

Formulas —

$$\Delta_{DL} = \frac{w\ell^4}{8EI}$$

$$\Delta_{LL} = \frac{P\ell^3}{3EI}$$

$$\Delta_{platform} = \frac{Pb^2}{6EI}(3\ell - b)$$

See sketch on sheet 4 for Loads

Δ_{DL} — $w = 55^{\#/'} = 4.58^{\#/''}$; $\ell = 73.5(12) = 882''$; $E = 10{,}400{,}000$; $I = 24{,}000$

$$\Delta_{DL} = \frac{4.58(882)^4}{8(10{,}400{,}000)(24{,}000)} = 1.39''$$

Δ_{LL} — $P = 1125^{\#}$; $\ell = 73.5' = 882''$; $E = 10{,}400{,}000$; $I = 24{,}000$

$$\Delta_{LL} = \frac{1125(882)^3}{3(10{,}400{,}000)(24{,}000)} = 1.03''$$

$\Delta_{platform}$ — $P = 175^{\#}$; $\ell = 882''$; $b = 21.5' = 258''$

$$\Delta_{platform} = \frac{175(258)^2[3(882) - 258]}{6(10{,}400{,}000)(24{,}000)} = \frac{175(66{,}564)(2388)}{6(10{,}400{,}000)(24{,}000)}$$

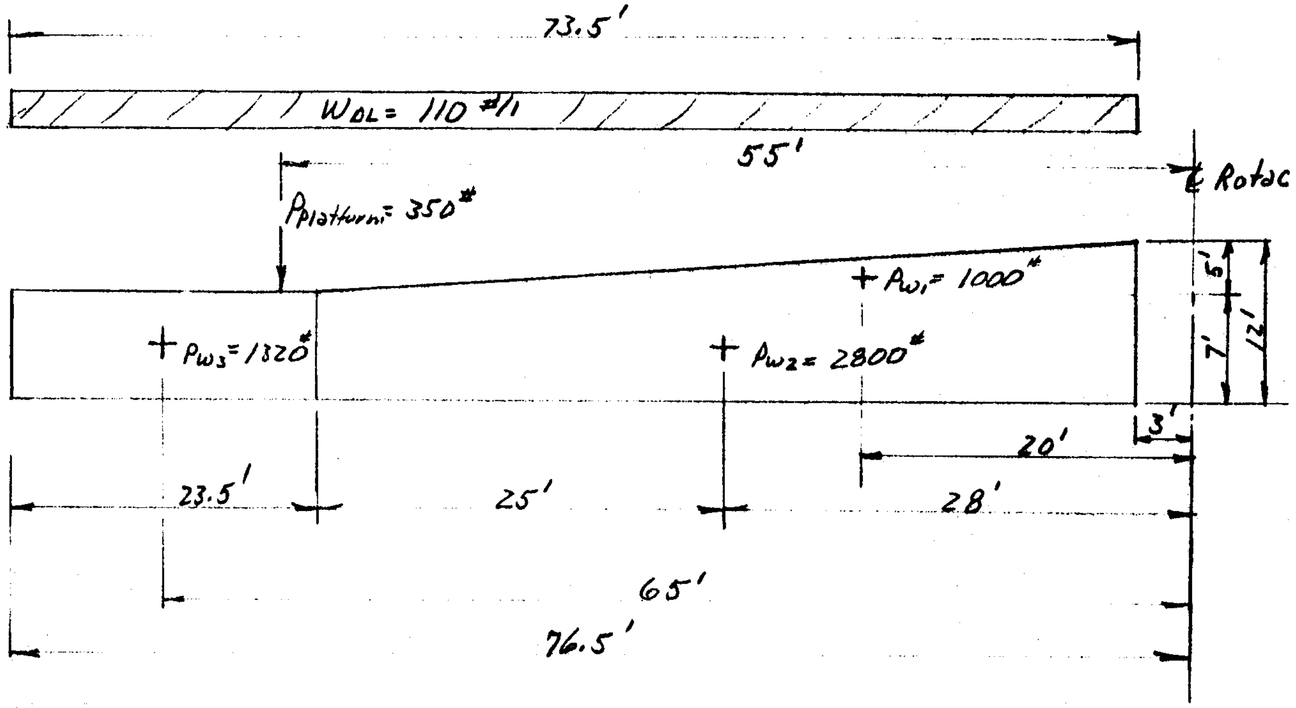
$$= .0188 = .02$$

$$\Delta_{Total} = 1.39 + 1.03 + .02 = \underline{2.44''}$$

Wrap-Around Access Arms

Mass Moment of Inertia

Case III presents critical condition for Mass I (DL + Max. wind)



Wind moment

Launch wind = 8 #/□' (see sheet 3)

$P_{w1} = \frac{1}{2}(5)(50)(8) = 1000$

$P_{w2} = 7(50)(8) = 2800$

$P_{w3} = 7(23.5)(8) = 1320$

$M_w = 1000(20) + 2800(28) + 1320(65)$

$20{,}000 + 78{,}400 + 85{,}800 = 184{,}200$ ft-lb

$= 2{,}210{,}000$ in.-lb

Mass Moment of Inertia

$I_m = [110(73.5)(39.75)^2 + 350(55)^2] \div 32.2$

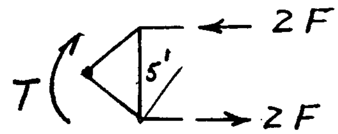
$= [12{,}800{,}000 + 1{,}060{,}000] \div 32.2 = 13{,}860{,}000 \div 32.2$

$= \underline{430{,}000}$ lb-ft-sec^2 $= \underline{5{,}170{,}000\ \text{lb}}$-in.-sec.^{2}

Minimum Time of Swing

There is a minimum time of swing for which the dynamic loading stresses will become more critical than the live load stresses. This is the critical time of swing.

Liveload force in Chord = 41,400# (see sht. 4)



$F = 41,400\#$

∴ Equating the force in the chords due to torque to the force due to liveload

$$\frac{T}{5} = 2F \; ; \; T = 5(2F) = 10F = 414,000 \text{ ft.-lb}$$

As the swing arm is in a stationary position, it is already overcoming the torque required to resist the wind loading. ∴ as it swings around the only additional torque which it must withstand is that due to overcoming the mass moment of inertia.

$I_m = 430,000$ lb-ft-sec^2
$\theta = 99.25° = 1.73$ rad.
$T = 414,000$ ft-lb
T with F.S. of 2 = 207,000 ft-lb

$$T = I_m \alpha = I_m \frac{2\theta}{t^2}$$

$$t^2 = \frac{I_m 2\theta}{T} = \frac{430,000(2)(1.73)}{207,000} = 7.2 \text{ sec}^2$$

$t = 2.69$ sec.

This indicates that to develop the force in the chords due to dynamic loading to equal that due to LL the arm would have to be accelerated through 99.25° in 2.69 sec. Or in other words, it is practically impossible to accelerate the arm fast enough for dynamic loading to become critical.

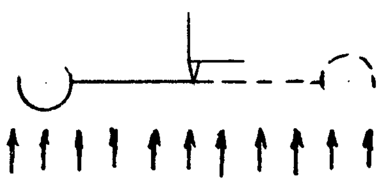
Wrap Around Access Arms

Torque Calculations

Since the access arms will be retracted prior to lift-off, the time of swing is somewhat arbitrary. The only criteria is that it be of sufficient magnitude that the torque requirements do not become excessive.

A 30 sec. time of swing will be assumed.

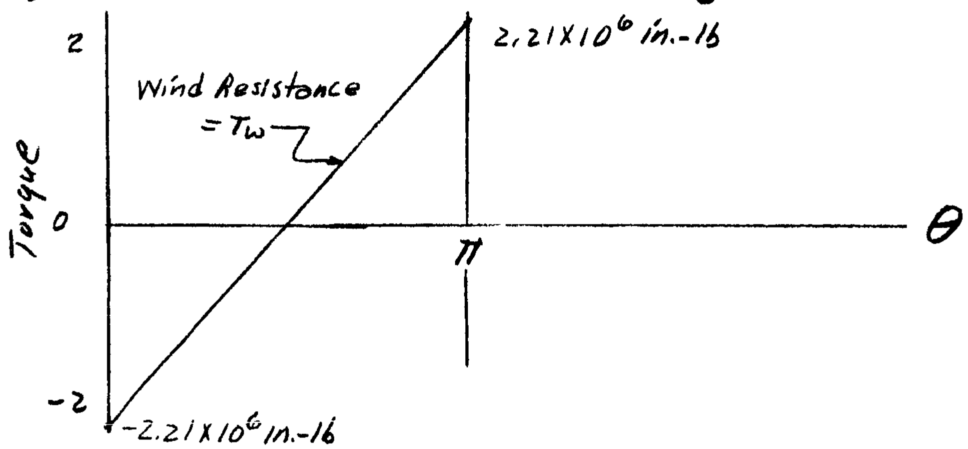
Wind Case No. 1



Assuming a total angle of swing of 180° instead of actual 198°

Max. Wind Moment = 2.21×10^6 in.-lb (see sht. 19)

Wind resistance to arm will be assumed to vary as a straight line instead of sinusoidally.



$\therefore$ Equation for line $T_W = 4.4\frac{\theta}{\pi} - 2.2$

Let –
T_W = Wind Torque
T_A = Actuator Torque
T_N = Net Torque
ΔT = Max. Value of T_{Net}

$\therefore T_N = T_A + T_W$

or $T_A = T_N - T_W$

Wrap-Around Access Arms

Torque Calculations

Wind Case No. 1 (cont.)

Assume T_N varies as a straight line

$\therefore T_N = -2\Delta T\frac{\theta}{\pi} + \Delta T$

so $T_A = -2\Delta T\frac{\theta}{\pi} + \Delta T - 4.4\frac{\theta}{\pi} + 2.2$

or $T_A = -(4.4 + 2\Delta T)\frac{\theta}{\pi} + (\Delta T + 2.2)$

Letting $I_m = J$

$$\alpha = \frac{T}{J} = \frac{T_N}{J} = \frac{1}{J}\left(-2\Delta T\frac{\theta}{\pi} + \Delta T\right)$$

$$\omega\, d\omega = \alpha\, d\theta$$

$$\frac{1}{2}\omega^2 = \frac{1}{J}\int\left(-2\Delta T\frac{\theta}{\pi} + \Delta T\right)d\theta$$

$$= \frac{1}{J}\left(-\frac{\Delta T\theta^2}{\pi} + \Delta T\theta\right)$$

or $\omega^2 = 2\frac{\Delta T}{J}\left(-\frac{1}{\pi}\theta^2 + \theta\right)$

$$\therefore \quad \omega = \sqrt{\frac{2\Delta T}{J}}\sqrt{\theta\left(1 - \frac{\theta}{\pi}\right)}$$

For $\theta = 0$ $\quad \omega = 0$

$\theta = \frac{\pi}{4}$ $\quad \omega = \sqrt{\frac{2\Delta T}{J}}\left(\frac{\sqrt{3\pi}}{4}\right)$

$\theta = \frac{\pi}{2}$ $\quad \omega = \sqrt{\frac{2\Delta T}{J}}\left(\frac{\sqrt{\pi}}{2}\right)$ $\quad \therefore \omega_{max.}$ occurs @ $\theta = \pi/2$

$\theta = \frac{3\pi}{4}$ $\quad \omega = \sqrt{\frac{2\Delta T}{J}}\left(\frac{\sqrt{3\pi}}{4}\right)$

$\theta = \pi$ $\quad \omega = 0$

$$\omega = \frac{d\theta}{dt} = \sqrt{\frac{2\Delta T}{J}}\sqrt{-\frac{1}{\pi}\theta^2 + \theta}$$

$$dt = \frac{d\theta}{\omega} \quad \text{or} \quad \int dt = \sqrt{\frac{J}{2\Delta T}}\int\frac{d\theta}{\sqrt{-\frac{1}{\pi}\theta^2 + \theta}}$$

$$\therefore t = \sqrt{\frac{J}{2\Delta T}}\sqrt{\pi}\,\sin^{-1}\left(\frac{2}{\pi}\theta - 1\right) + C$$

Evaluating C for $\theta = 0$ @ $t = 0$

$$t = \sqrt{\frac{J}{2\Delta T}}\sqrt{\pi}\left[\sin^{-1}\left(\frac{2}{\pi}\theta - 1\right) - 3\frac{\pi}{2}\right]$$

Wrap-Around Access Arms

Torque Calculations

Wind Case No. 1 (Cont.)

t is a max. when $\theta = \pi$

$$t = \sqrt{\frac{J}{2\Delta T}}\sqrt{\pi}\left[\sin^{-1}\left(\frac{2}{\pi}\theta - 1\right) - 3\frac{\pi}{2}\right]$$

$$t_{max} = \sqrt{\frac{J}{2\Delta T}}\sqrt{\pi}\left[\sin^{-1}(2-1) - 3\frac{\pi}{2}\right]$$

To obtain a positive figure for "t" the value of the brackets must be positive or the arcsin term must be equal to or greater than $3\pi/2$. When $\theta = 0$, $t = 0$ and the value of the arcsin term equals $3\pi/2$. Therefore, for evaluating the arcsin term, $3/2\,\pi$ will be considered as the starting point. Thus, for the above t_{max} expression, the next point at which the arcsin term has a value of 1 is at $\theta = \frac{5}{2}\pi$

$$\therefore t_{max} = \sqrt{\frac{J}{2\Delta T}}\sqrt{\pi}\left[\frac{5}{2}\pi - \frac{3}{2}\pi\right] = \sqrt{\frac{J}{2\Delta T}}\sqrt{\pi}\,\pi$$

$$t^2_{max.} = \frac{J}{2\Delta T}\pi^3$$

$$\Delta T = \frac{J\pi^3}{2t^2_{max}}$$

$J = 5.17 \times 10^6$ in-lb-sec^2

For $t_{max} = 30$ sec

$$\Delta T = \frac{5.17 \times 10^6 (3.14)^3}{2(30)^2} = 89{,}000 \text{ in.-lb}$$

$$\omega_{max} = \frac{\sqrt{\pi}}{2}\sqrt{\frac{2\Delta T}{J}} = .885\sqrt{\frac{2(.089)}{5.17}} = .885\sqrt{.0345} = .885(.1858)$$

$\omega_{max} = .164$ rad/sec

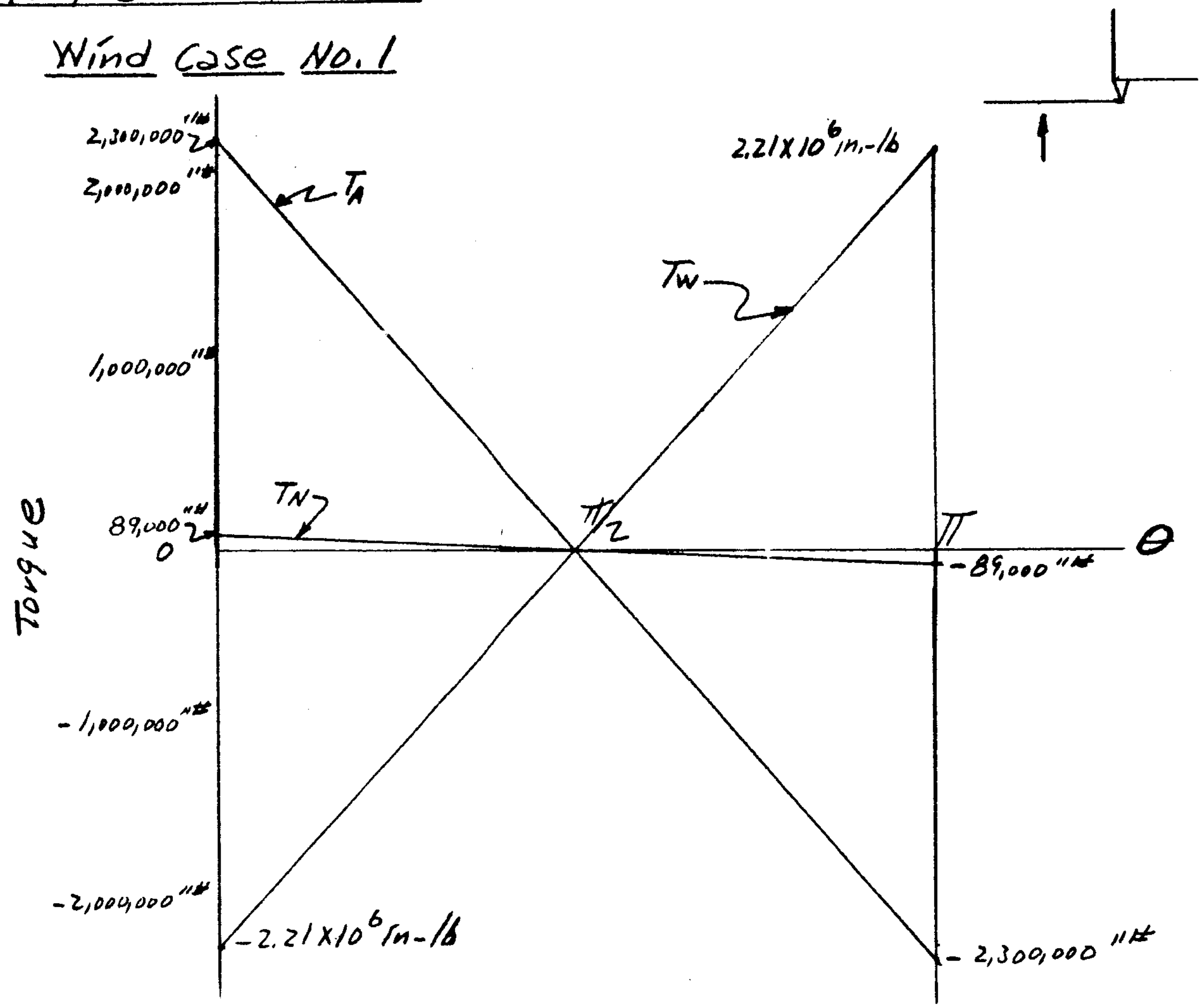
$\therefore$ Actuator must Produce $T_A = T_N - T_W = \Delta T - T_W$ where $\Delta T = (T_N)_{max}$

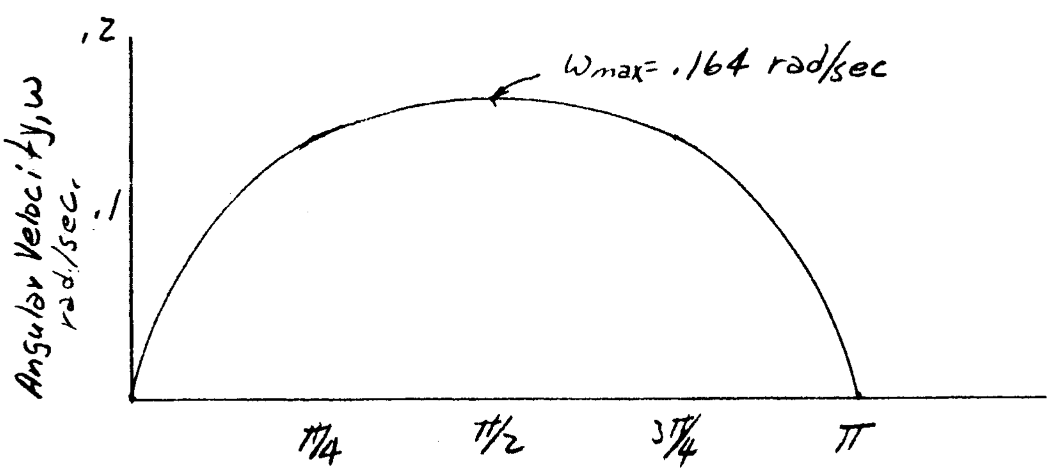
$\therefore T_A = 89{,}000 - (-2{,}210{,}000) = \underline{2{,}299{,}000 \text{ in.-lb}}$

Wrap-Around Access Arms

Torque Calculations

Wind Case No. 1





Wrap-Around Access Arms

Torque Calculations

No Wind

The torque accelerating the arm will be the same as T_A for Wind Case No. 1 (see sht. 24) $T_A = 2{,}300{,}000$ in lb

This torque will follow the curve $T = -4.6\frac{\theta}{\pi} + 2.3$ until $\omega = \omega_{max}$, then flow restricting valve will cut in. ω_{max} is the ω_{max} determined for Wind Case No. 1.

The θ when $\omega = \omega_{max}$ must be determined

$\omega_{max} = .164$ rad/sec.

ω for no Wind

$$\frac{1}{2}\omega^2 = \int \frac{T}{J}\,d\theta = \frac{1}{J}\int\left(-4.6\frac{\theta}{\pi} + 2.3\right)d\theta$$

$$\frac{1}{2}\omega^2 = \frac{1}{J}\left(-\frac{2.3\theta^2}{\pi} + 2.3\theta\right)$$

$$\frac{1}{2}(.164)^2 = \frac{-2{,}300{,}000\,\theta^2}{5.17\times10^6(3.14)} + \frac{2{,}300{,}000\,\theta}{5{,}170{,}000}$$

$$.0134 = -.142\,\theta^2 + .445\theta$$

$$.142\theta^2 - .445\theta + .0134 = 0$$

$$\theta = \frac{.445 \pm \sqrt{.445^2 - 4(.142)(.0134)}}{2(.142)}$$

$$= \frac{.445 \pm \sqrt{.190}}{.284} = \frac{.445 \pm .437}{.284} = \frac{.008}{.284} = .0282 \text{ rad.}$$

$$\theta = 1.6^\circ$$

$\therefore \omega = \omega_{max}$ @ $\theta = 1.6^\circ$

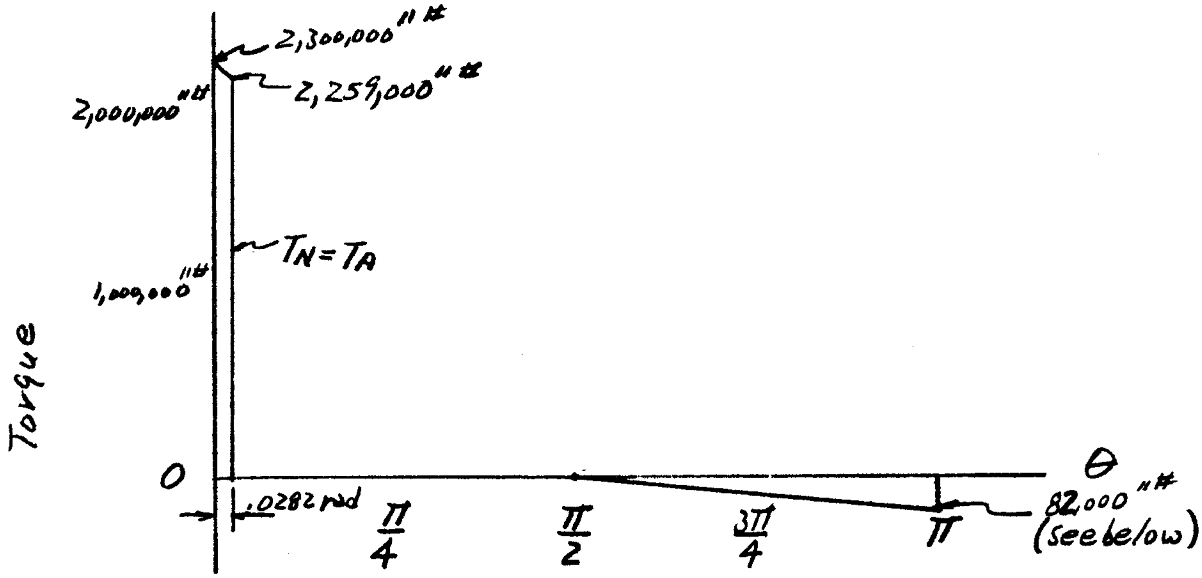
T @ $\theta = .0282$ rad

$$T = -4.6\frac{\theta}{\pi} + 2.3 = -\frac{4.6(.0282)}{3.14} + 2.3 = .0413 + 2.3 = 2.259$$

Wrap-Around Access Arms

Torque Calculations

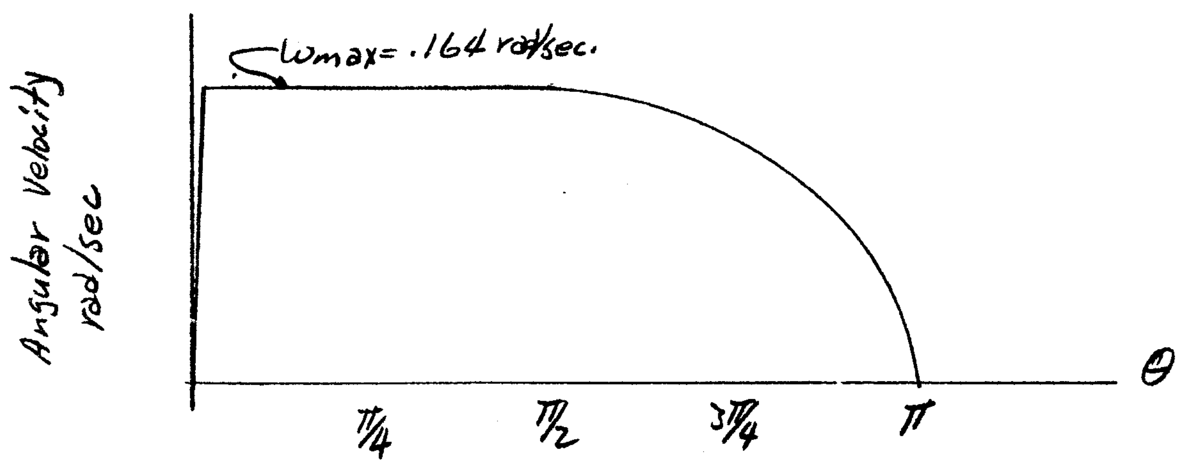
No Wind



Area under curve = energy. Decelerating energy must = accelerating energy

$$\left(\frac{2.3+2.26}{2}\right).0282 = \frac{1}{2}\left(\frac{3.14}{2}\right)T$$

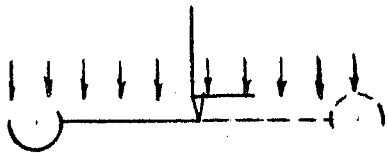
$.0643 = .785T$ or $T = .082 = 82{,}000$ in.-lb for deceleration



Wrap-Around Access Arms

Torque Calculations

Wind case No. 2



In this case, both the wind and the actuator supplies torque until the flow restricting valve cuts in.

so $T_N = T_W + T_A$

$T_W = -4.4\frac{\theta}{\pi} + 2.2 \qquad (T_W)_{max} = 2{,}200{,}000''\#$

$T_A = -4.6\frac{\theta}{\pi} + 2.3 \qquad (T_A)_{max.} = 2{,}300{,}000''\#$

or $T_N = -9\frac{\theta}{\pi} + 4.5$ until flow restricting valve cuts in

$\omega d\omega = \alpha d\theta = \frac{T}{J} d\theta = \frac{1}{J}\left(-9\frac{\theta}{\pi} + 4.5\right) d\theta$

$\frac{1}{2}\omega^2 = \frac{1}{J}\left(-\frac{4.5\theta^2}{\pi} + 4.5\theta\right)$

$\omega_{max} = .164$ rad/sec (see sht. 23)

Find θ when $\omega = \omega_{max}$.

$\frac{1}{2}(.164)^2 = \frac{1}{5.17}\left(-\frac{4.5}{3.14}\theta^2 + 4.5\theta\right)$

$\frac{1}{2}(.164)^2(5.17) = -1.43\theta^2 + 4.5\theta$

$.0695 = -1.43\theta^2 + 4.5\theta$

or $1.43\theta^2 - 4.5\theta + .0695 = 0$

$\theta = \frac{4.5 \pm \sqrt{(4.5)^2 - 4(1.43)(.0695)}}{2(1.43)} = \frac{4.5 \pm 4.42}{2.86} = \frac{.08}{2.86} = .028$

θ @ $\omega = \omega_{max.} = .028$ rad. $= 1.6^\circ$

T_N @ $\theta = .028$ rad $= -\frac{9(.028)}{3.14} + 4.5 = -.0803 + 4.5 = 4.42$

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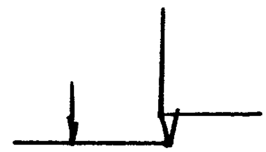
Wrap-Around Access Arms

Torque Calculations

Wind Case No. 2

$T_N = T_A + T_W$



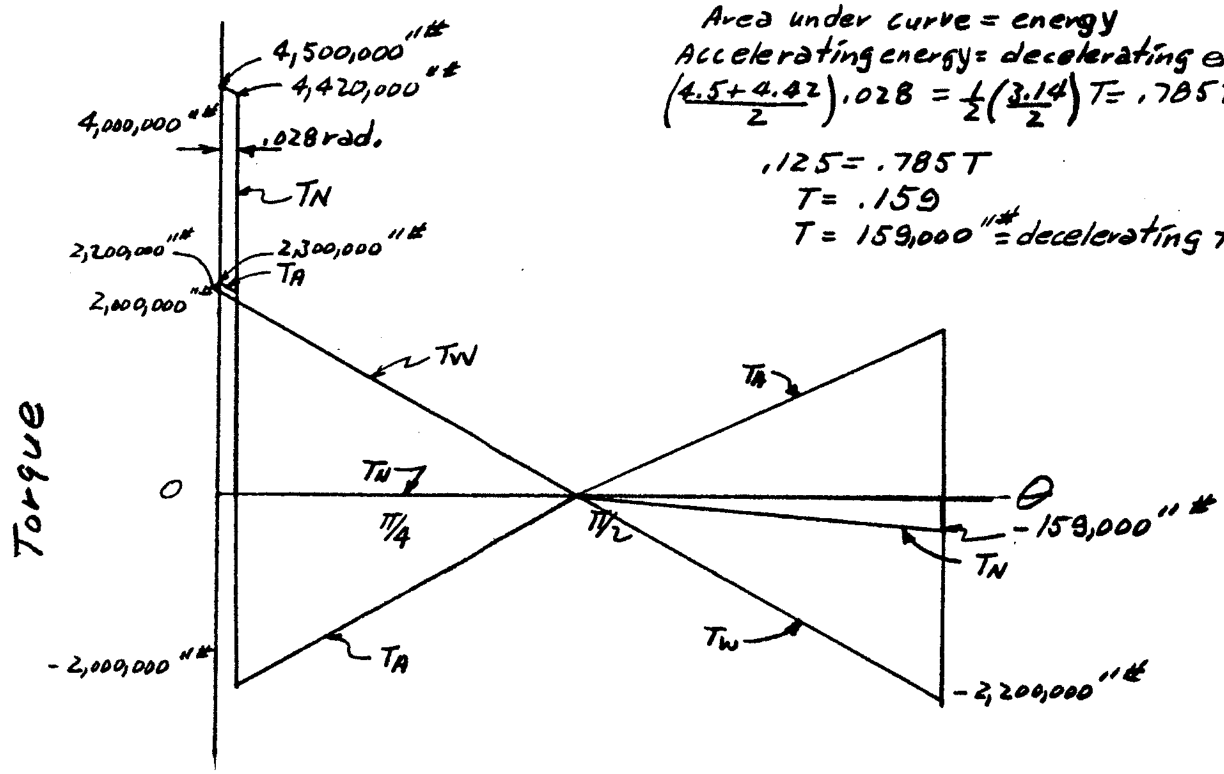
Area under curve = energy
Accelerating energy = decelerating energy

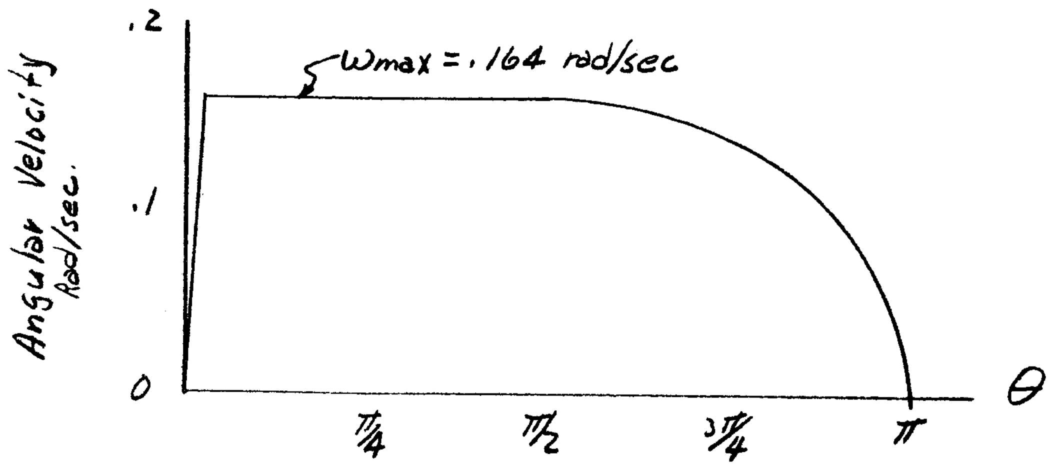
$\left(\frac{4.5+4.42}{2}\right).028 = \frac{1}{2}\left(\frac{3.14}{2}\right)T = .785T$

$.125 = .785T$

$T = .159$

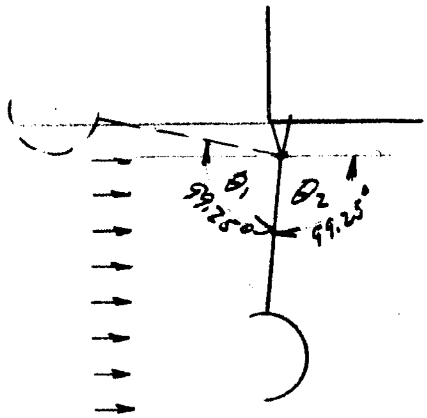
$T = 159{,}000$ ''# = decelerating torque





Wrap-Around Access Arms

Torque Calculations (Cont.)



The wind in the direction shown aids in accelerating the arm during almost all of its entire swing. Since the wind force and thus the wind torque varies sinusoidally, the RMS value of wind Torque will be .707 the max. value

$$\text{Wind } T_{Avg} = .707\,(2{,}210{,}000) = 1{,}565{,}000 \text{ in.-lb.}$$

constantly applied torque = 2,289,500 in.-lb thru $\frac{1}{2}$ angle of rotation

$I_m = 5{,}170{,}000$

$$T = I_m \alpha \quad \therefore \quad \alpha_1 = \frac{T}{I_m} = \frac{2{,}289{,}000}{5{,}170{,}000} = .443 \text{ rad/sec}^2$$

$$\theta = \frac{\omega_f^2 - \omega_i^2}{2\alpha} \quad \text{But } \omega_i = 0 \quad \therefore \theta = \frac{\omega_f^2}{2\alpha} \quad \text{Or } \omega_f^2 = 2\alpha\theta$$

$$\alpha = \frac{\omega_f^2}{2\theta}$$

$$\therefore \omega_f^2 = 2(.443)(1.732) = 1.537 \text{ rad./sec}$$

$$\alpha_2 = \frac{\omega_f^2}{2\theta} = \frac{1.537}{2(1.732)} = .443 \text{ rad/sec}^2$$

$\therefore$ Deceleration Torque = Wind moment + $I_m \alpha_2$

= 1,565,000 + 5,170,000 (.443)

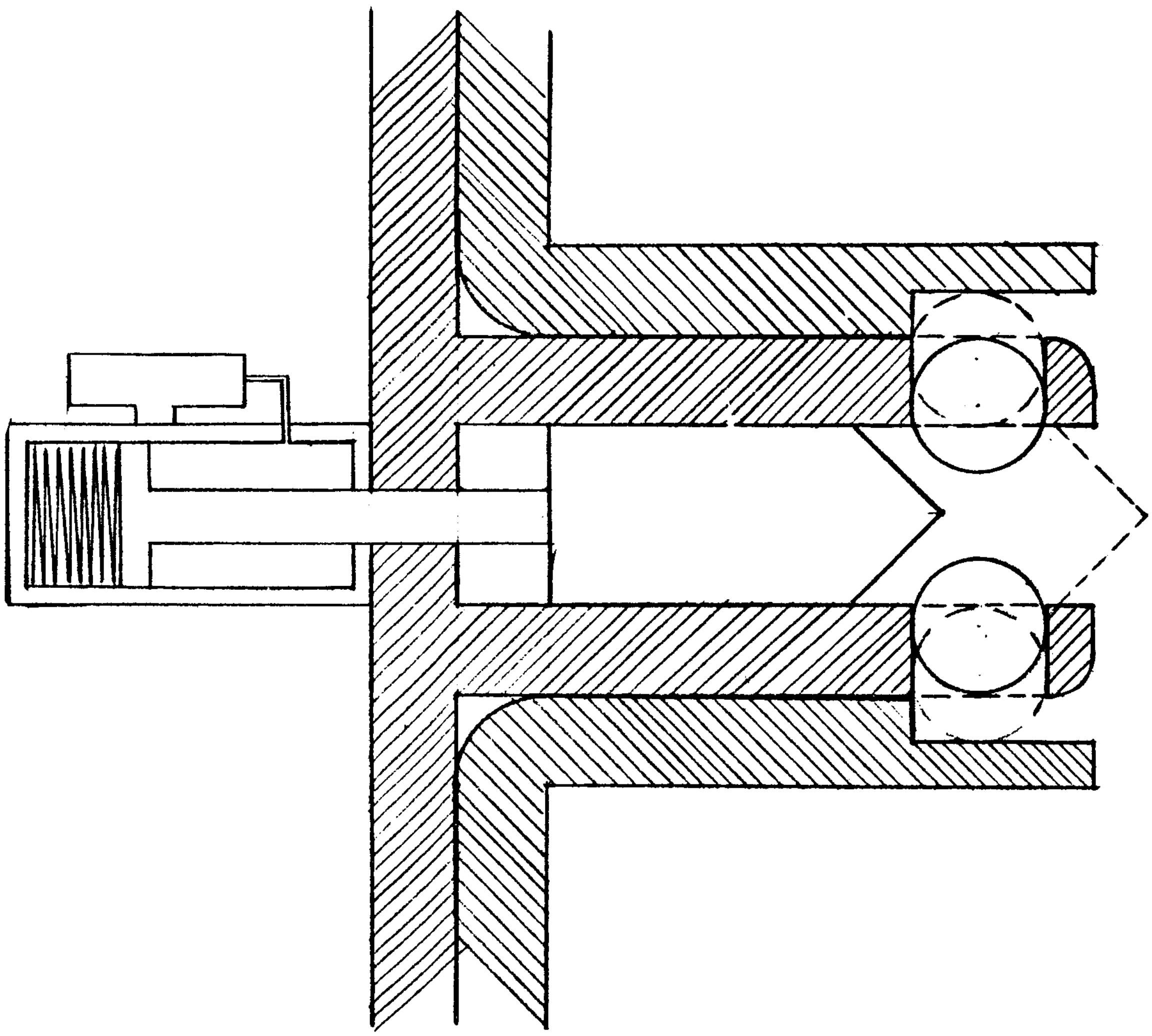
= 1,565,000 + 2,289,000

= 3,854,000 in.-lb.

However, it is understood that a flow restricting valve will prevent the arm from reaching an "ω" such that this torque is necessary.

Wrap-Around Access Arms

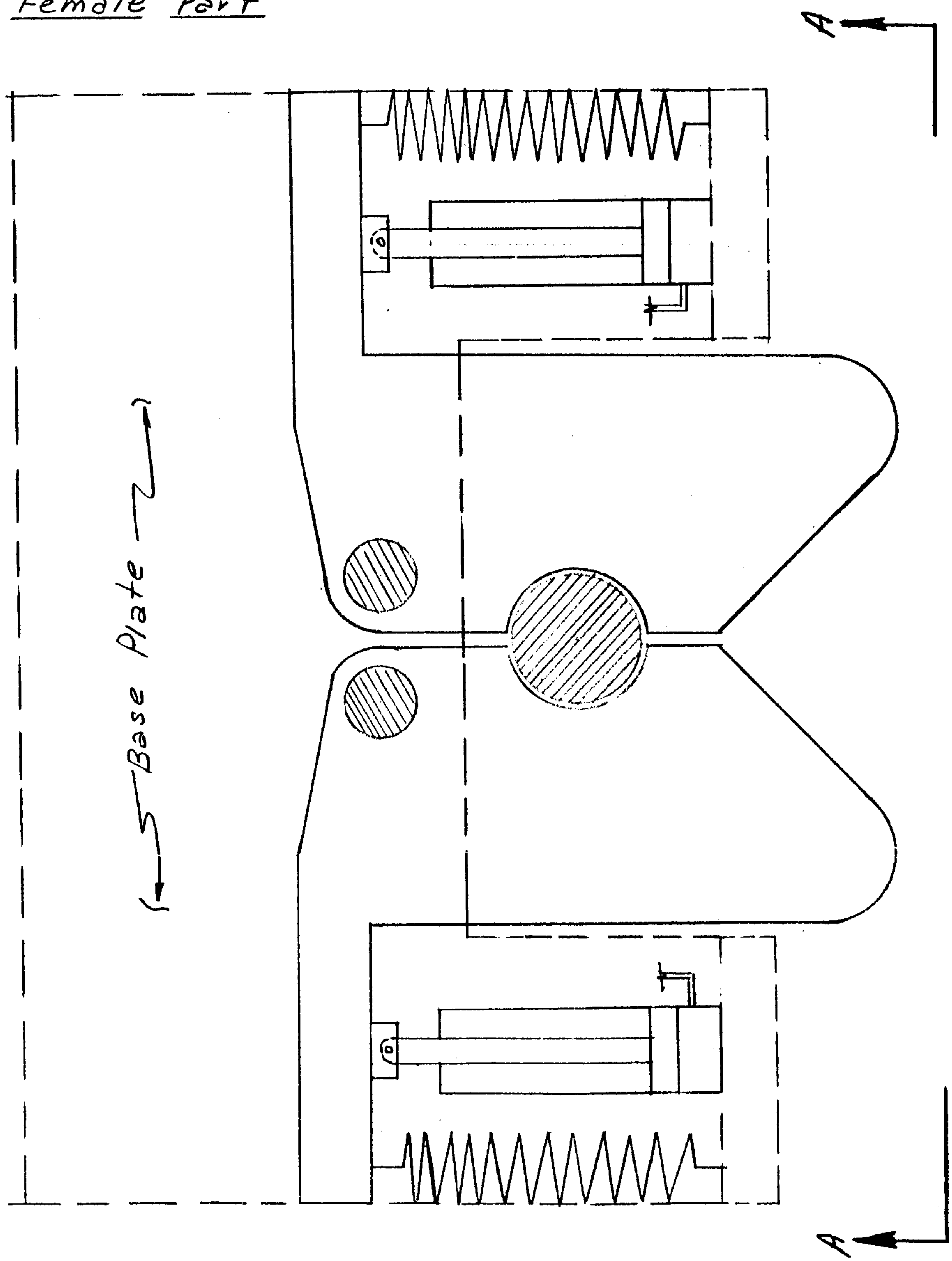
Automatic Lock-Ball Type Latching Device No. 1



Wrap-Around Access Arms

Automatic Latching Device No. 2

Female Part



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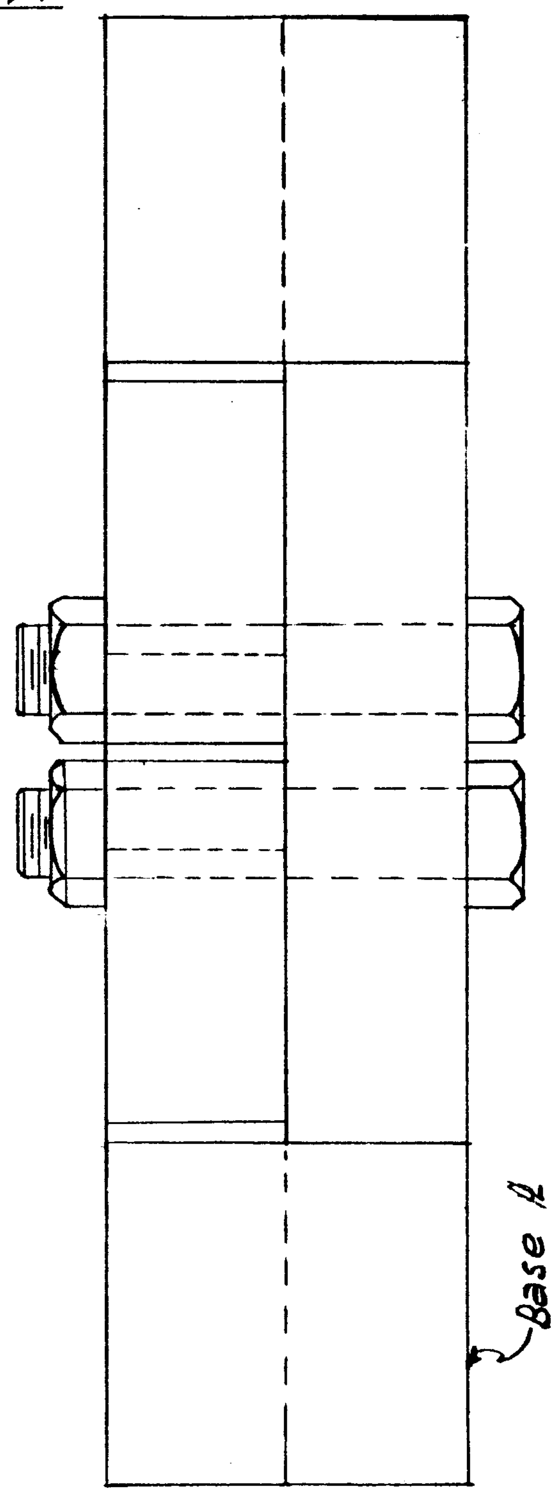
Wrap-Around Access Arms
Automatic Latching Device NO. 2

Female Part

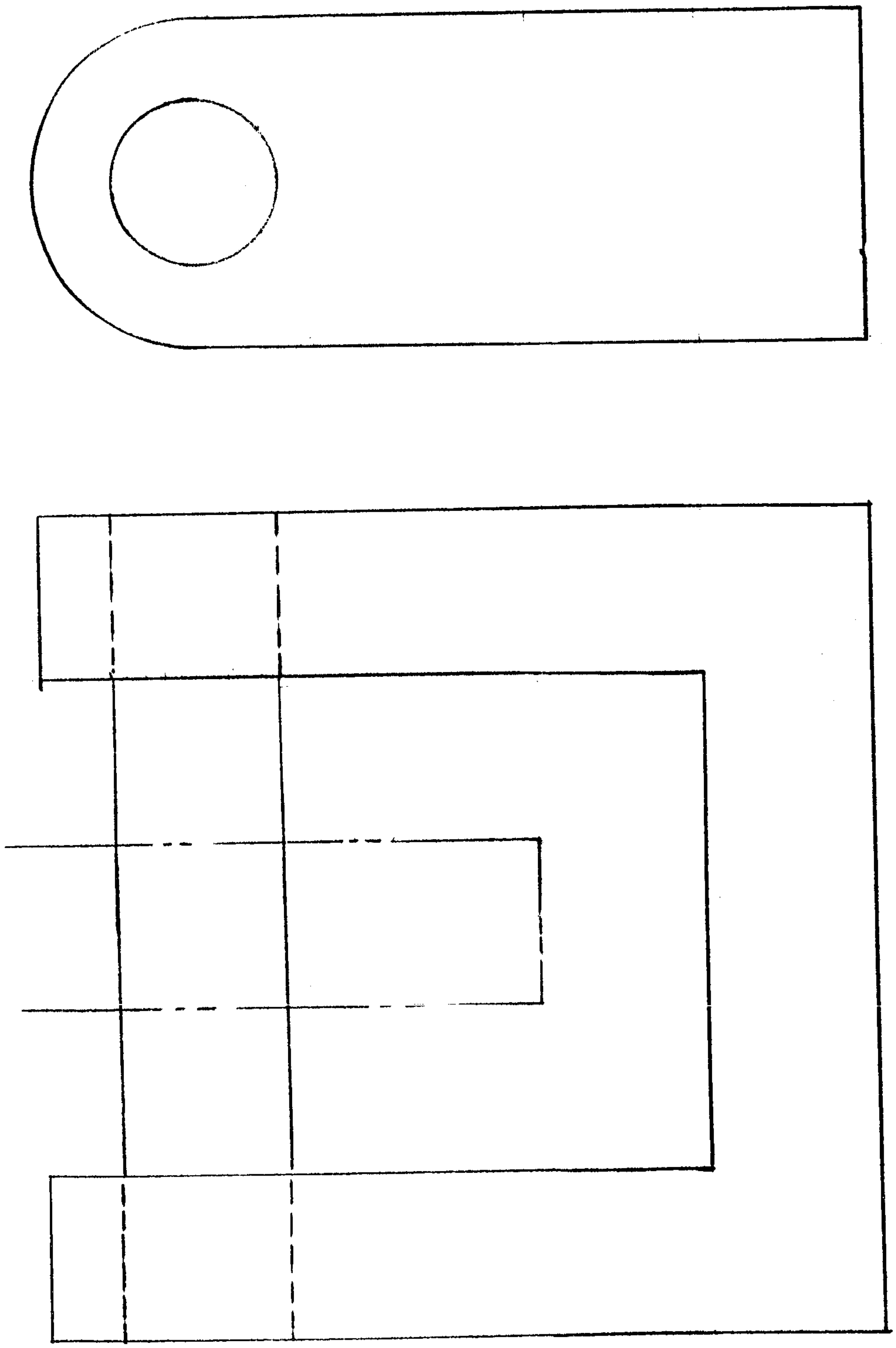


VIEW A-A

Wrap-Around Access Arms

Automatic Latching Device No. 2

Male Part



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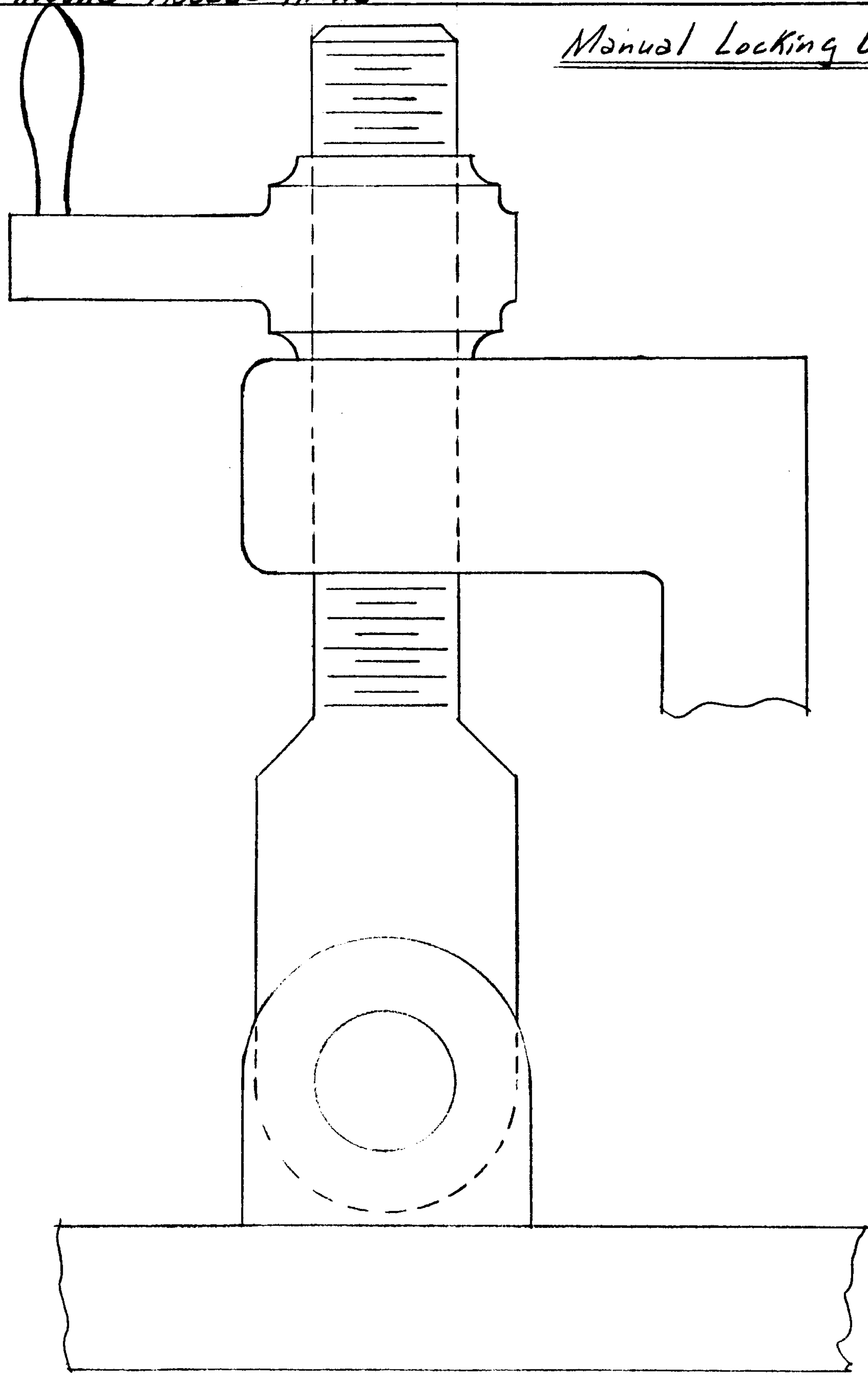
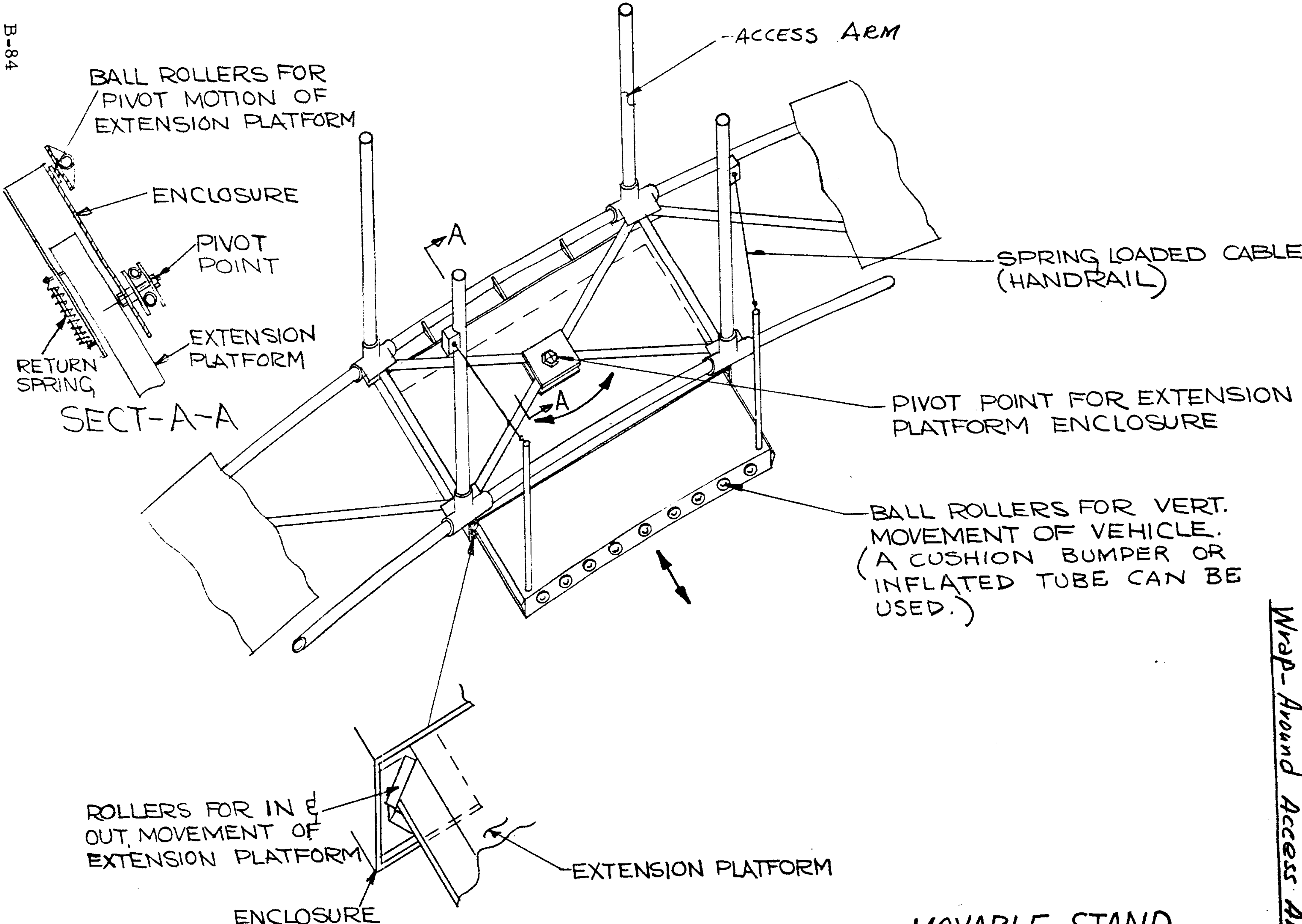
Wrap-Around Access Arms

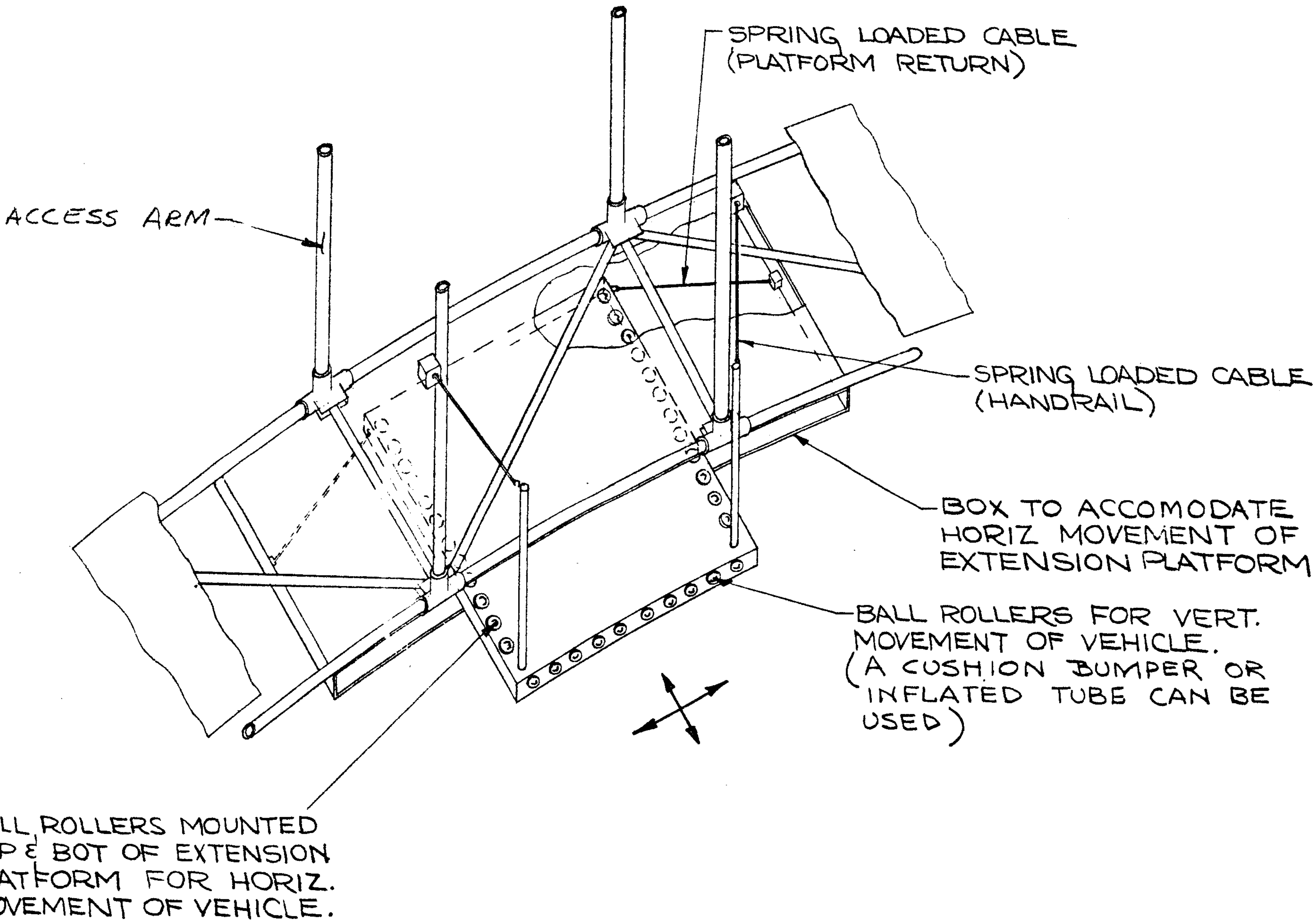
Manual Locking Device





MOVABLE STAND

LT 6/11/62



MOVABLE STAND

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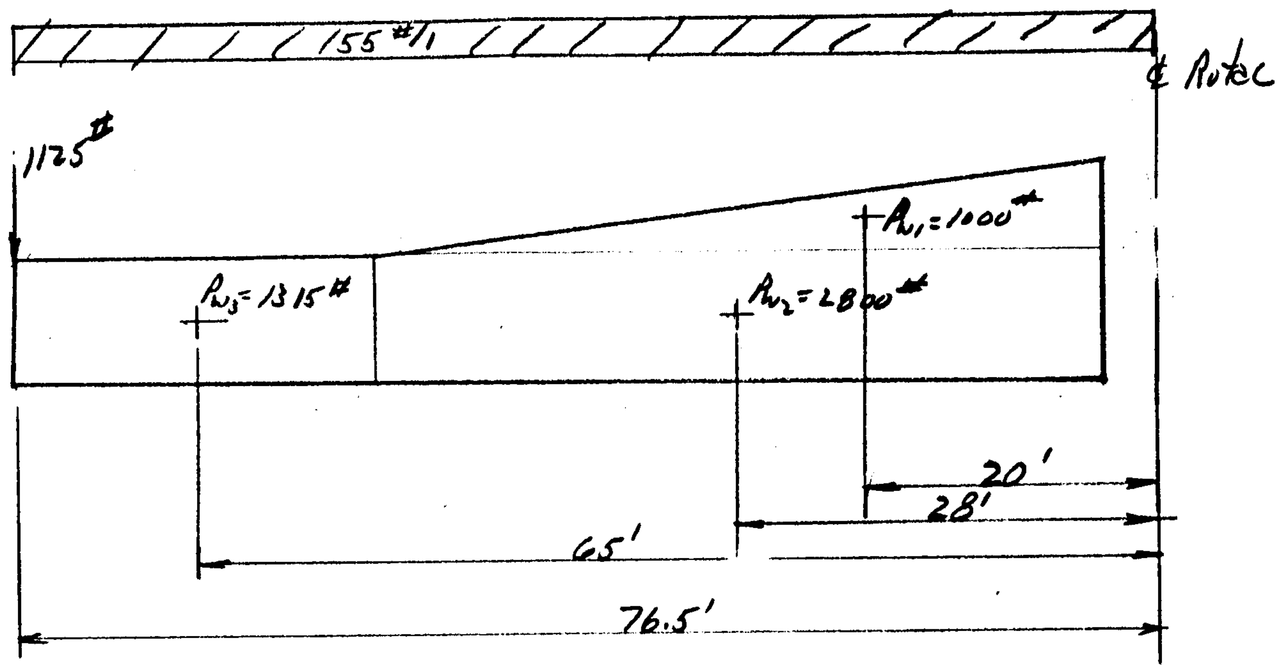
Wrap-Around Access Arm

Connection to Tower



Vertical Mom. about ℄ Rotac

$$W_{DL} = 55(76.5)\left(\frac{76.5}{2}\right)\overset{L.F.}{(2)} = 322{,}000$$

$$P_{LL} = 1125(76.5)(6) = \underline{517{,}000}$$

$$839{,}000 \text{ ft-lb}$$

Horizontal Moment about ℄ Rotac

$$P_{w_1} = 1000(20)(2) = 40{,}000$$

$$P_{w_2} = 2800(28)(2) = 157{,}000$$

$$P_{w_3} = 1315(65)(2) = \underline{171{,}000}$$

$$368{,}000 \text{ ft-lb}$$

Vertical Shear

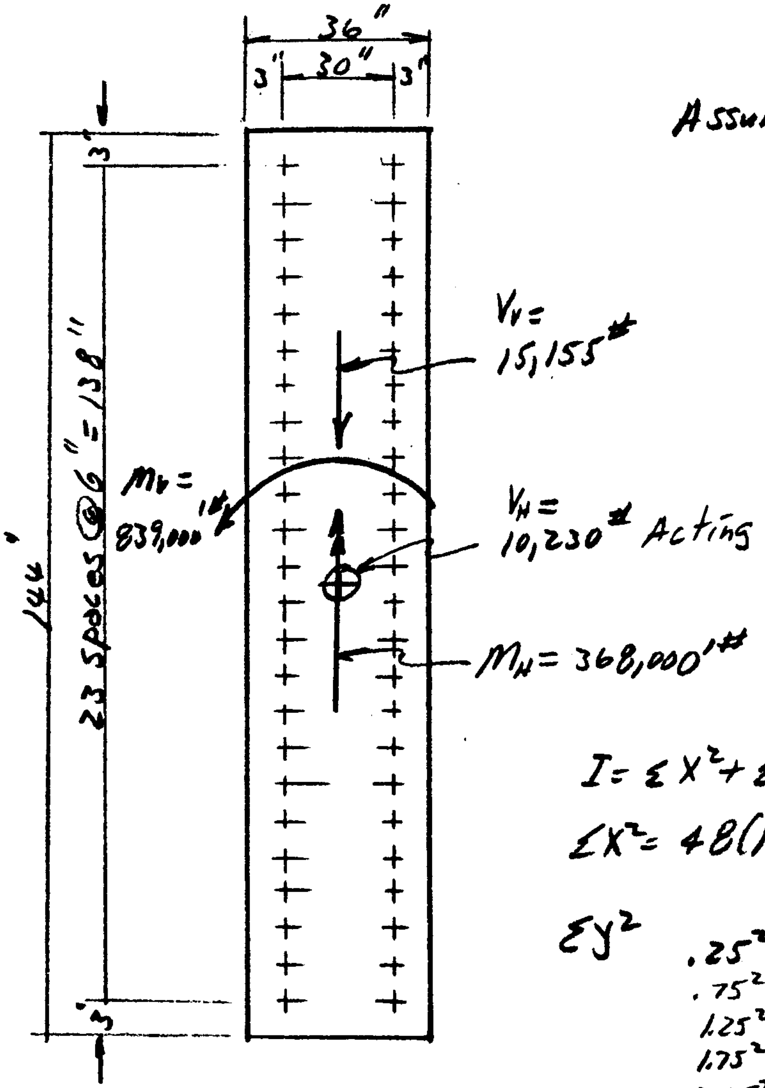
$$V_F = 55(76.5)(2) + 1125(6) = 15{,}155^{\#}$$

Horizontal Shear

$$V_H = (1000 + 2800 + 1315)2 = 10{,}230^{\#}$$

Wrap Around Access Arm

Connection to Tower



Assuming $\frac{3}{4}$" High Strength Bolts

Shear Allowable = 9.72^K

Tension Allowable = 17.67^K

$I = \Sigma X^2 + \Sigma y^2$

$\Sigma X^2 = 48(1.25)^2 = 75$

Σy^2

$.25^2 =$	.0625
$.75^2 =$	.5625
$1.25^2 =$	1.5625
$1.75^2 =$	3.0625
$2.25^2 =$	5.0625
$2.75^2 =$	7.5625
$3.25^2 =$	10.5625
$3.75^2 =$	14.0625
$4.25^2 =$	18.0625
$4.75^2 =$	22.5625
$5.25^2 =$	27.5625
$5.75^2 =$	33.0625
	143.75

$4(143.75) = 575$

$\Sigma x^2 + \Sigma y^2 = 75 + 575 = 650$

Wrap-Around Access Arm

Connection to Tower

Load on critical bolt due to M_V

$$H = \frac{M_V y}{I} = \frac{839{,}000\,(5.75)}{650} = 7440^{\#} \text{ Hor. Shear}$$

$$V = \frac{M_V X}{I} = \frac{839{,}000\,(1.25)}{650} = 1615^{\#} \text{ vert. shear}$$

Load on Critical bolt due to M_H

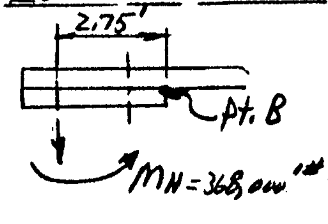


Plate will be assumed to rotate about Pt. B

∴ Tension in one Bolt,

$$T = \frac{368000}{2.75(24)} = 5580^{\#} \text{ tension}$$

Load on Critical Bolt due to V_V

$$V = \frac{15{,}155}{48} = 316^{\#} \text{ vert. shear}$$

Load on critical Bolt due to V_H

$$T = \frac{10{,}230}{48} = 213^{\#} \text{ tension}$$

Summation of Forces

Total Vert. Shear $= 1615 + 316 = 1931^{\#}$

" Hor. " $= \text{— — —} = 7440^{\#}$

Resultant Shear $= \sqrt{7440^2 + 1931^2} = 7680^{\#} < 9.72^{K}$ ∴ OK

Total tension $= 5580 + 213 = 5793^{\#} < 17.67^{K}$ ∴ OK

Basic Egress Platform

Cost Estimate

Tubing

(All lengths will be scaled from working drawing.)
All tubes have 1/4" thick walls except 1½"φ.

5½"φ Tube	200'	@ 4.85 #/1 =	971 #
4"φ Tube	126'	@ 3.46 #/1 =	436 #
3½"φ Tube	367'	@ 3.00 #/1 =	1101 #
3"φ Tube	126'	@ 2.54 #/1 =	320 #
2½"φ Tube	138'	@ 2.08 #/1 =	287 #
2"φ Tube	150'	@ 1.62 #/1 =	243 #
1½"φ x 1/8" walls Tube	168'	@ .64 #/1 =	108 #
			3466 #

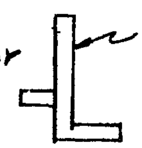
Connectors

Total of 66 connectors
Wt. per connector say 5# Avg.
5(66) = 330#

Flooring

$4.5(50) + \frac{3.14}{2}(16.67^2 - 12.15^2) = 225 + 203 = 428$ □'

Flooring Support



Weight per foot 6 x 3½ x 5/16 L = 3.39#
" " " 2 x 1/4 Bar = .59#
3.98#/1

No. of linear feet = 168'
(All lengths scaled from working drawing)

Total weight = 168(3.98) = 668#

Basic Egress Platform

Cost Estimate

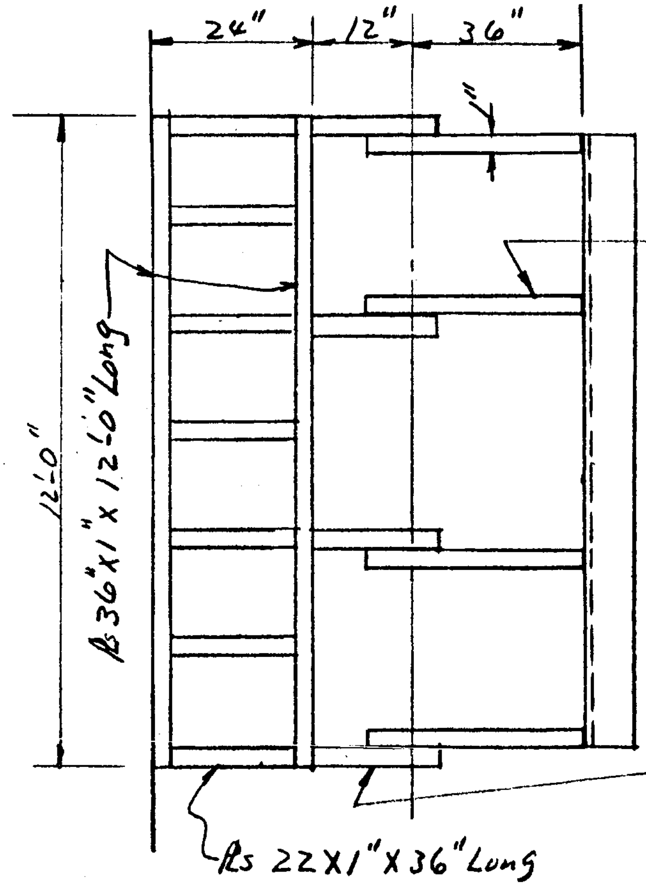
Wire Mesh

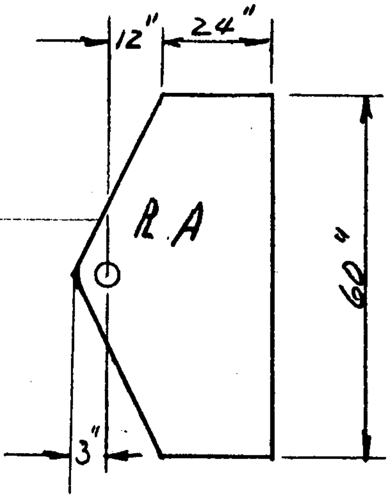
Area = 1378 □'

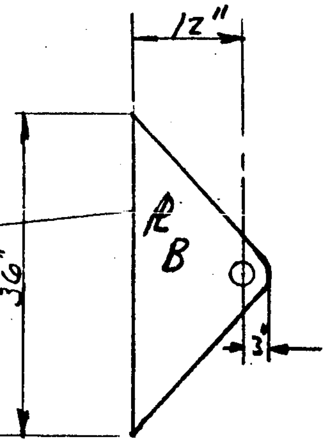
(All lengths scaled from working drawing)

Truss-to-Tower Connection

configuration and Dimensions are for cost estimate only







Assuming Mat'l is 4130 steel
Weight = 490#/Ft³ = .283 #/in³

Wt. of 36x1"x12'-0" Long PLs = 36(1)(144)(.283)(2) = 2940#

Wt. of 22x1 x36" Long PL = 22(1)(36)(.283)(7) = 1570#

Wt. of PL A = [24(60)(1)(.283) + ½(60)(15)(1)(.283)] 4
= [408 + 128] 4 - - - - - - - = 2144#

Wt. of PL B = [½ (36)(15)(1)(.283)] 4 = 306

6960#

Basic Egress Platform

Cost Estimate

Bill Of Material

Description	Unit Price	Quantity	Amount
Tubing			
Al. Alloy, 6061-T6			
5½" Dia. X.25 Wall	.747/lb	971 lb	725.00
4" Dia. X.25 Wall	.776/lb	436 lb	338.00
3½" Dia. X.25 Wall	.750/lb	1101 lb	826.00
3" Dia. X.25 Wall	.791/lb	320 lb	253.00
2½" Dia. X.25 Wall	.826/lb	287 lb	237.00
2" Dia. X.25 Wall	.826/lb	243 lb	201.00
1½" Dia X.125 Wall	1.001/lb	108 lb	108.00
Hardware; Nuts, Bolts, Rivets, Etc.			200.00
Mesh; Stainless Steel			
1" squares	2.50 □'	1500 □'	3750.00
Flooring; Expanded Al. Grating	2.00 □'	428 □'	856.00
Raw Material			
Almag 35	.375/lb	330 lb	124.00
Al. Alloy Angle & Bar, 6061-T6	1.10/lb	668 lb	735.00
Steel, 4130	.4032/lb	6960 lb	2806.00
Movable Stands (Assuming three Stands Per Platforms)	L.S.		6000.00
			$17,159.00

Basic ~~Egress~~ Access ~~Platform~~ ARM

Cost Estimate

Estimated Labor Cost

Category	Man-Hours	Average Rate	Tot. Labor Cost
Sheet Metal	700	5.95	4165.00
Machine Shop	1000	5.85	5850.00
Fab-Weld	900	6.01	5481.00
Painting	120	5.30	636.00
Inspection	275	4.95	1361.00
Quality Control	80	6.50	520.00
			18,013.00

Material cost	17,159.00
Labor cost	18,013.00
Profit, 10%	3,517.00
Total cost	$38,689.00

Above Total Cost of $38,689.00 is for one ~~Platform~~ ARM

Total Cost for one set of ~~Platforms~~ ARMS = $77,378.00

Use 77,400.

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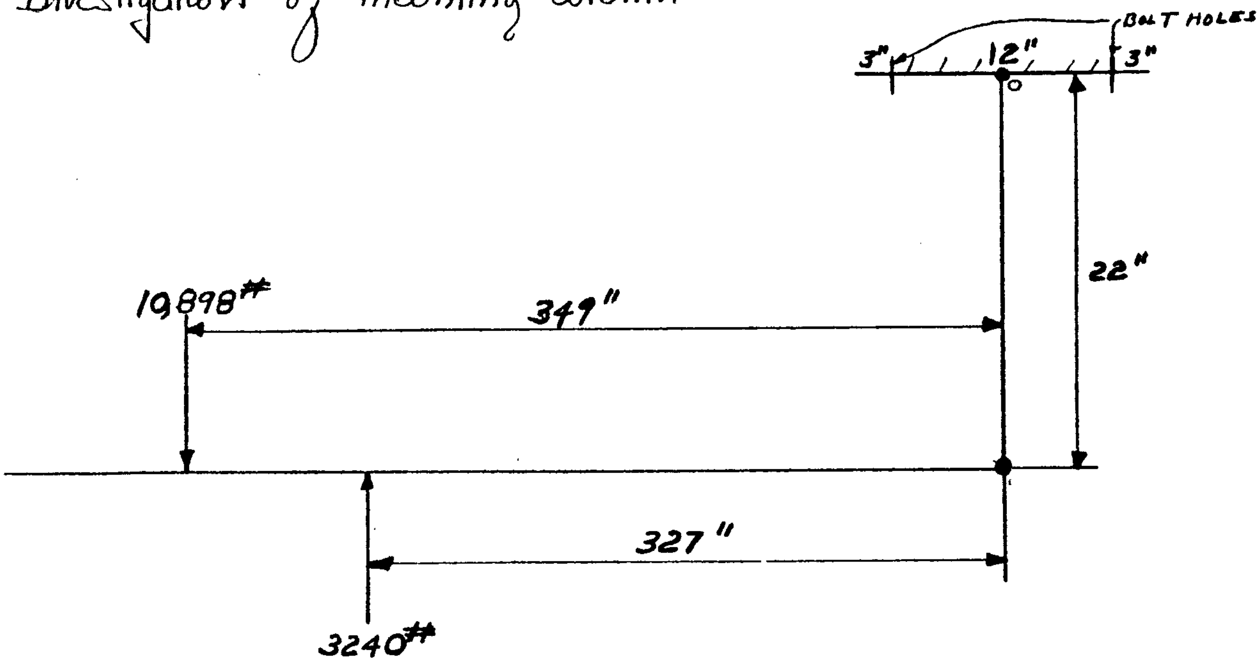
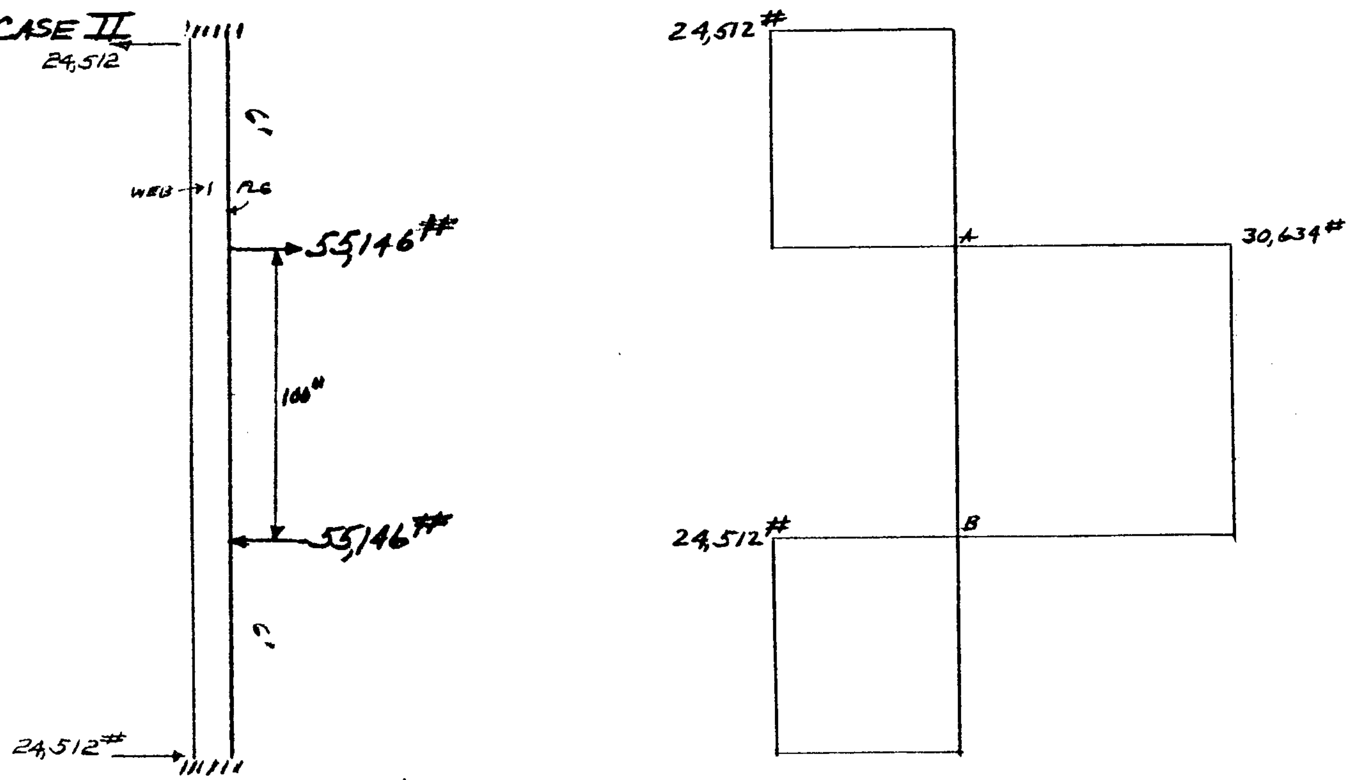
Investigation of mounting column



CASE II



$M_A = -(24{,}512 \times 6) = -147{,}072$ FT-LBS

$M_B = -147{,}072 + (30{,}634 \times 8) = 98{,}000$ FT.LBS

$\frac{M}{S} = \frac{I}{C} = \frac{1{,}176{,}000}{20{,}000} = 58.8\ IN^3$ USE 12WF53#

SHIELD & SUPPORTS

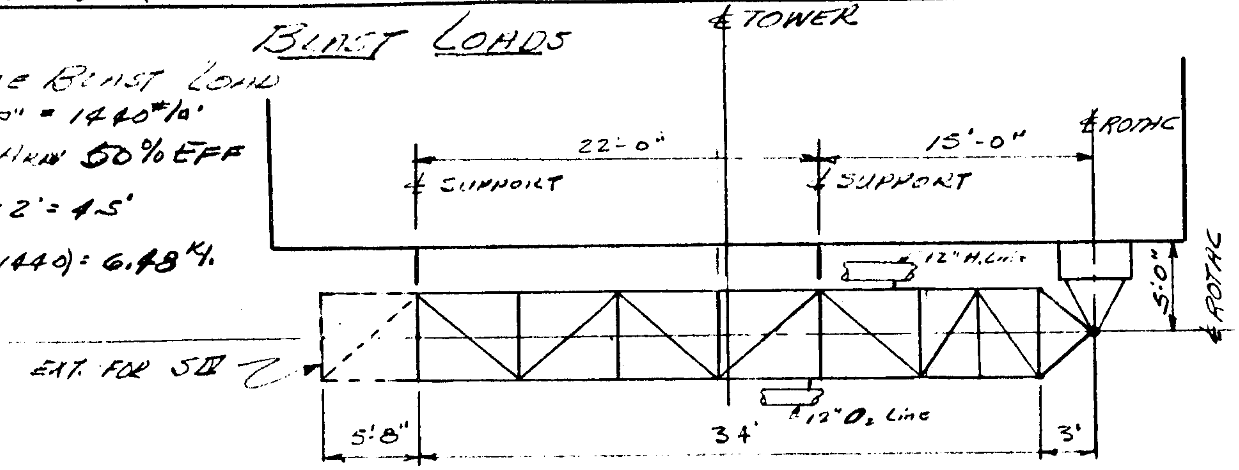
BLAST LOADS

Assume Blast Load
$= 10^{\#}/\square'' = 1440^{\#}/\square'$

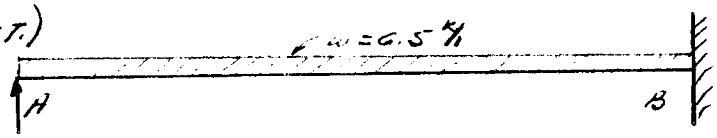
Assume Heav 50% EFF

$.5(5) + 2' = 4.5'$

$W = 4.5(1440) = 6.48^{K}/'$



Case I (1 support - No Ext.)



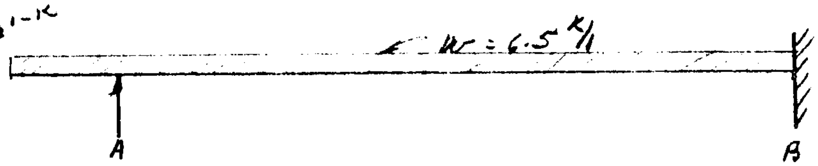
$V_A = \frac{3}{8}(6.5)(37) = 90.2^{K}$

$V_B = \frac{5}{8}(6.5)(37) = 150.2^{K}$

$M_B = \frac{1}{8}(6.5)(37)(37) = 1112^{1-K}$

$+M = \frac{9}{128}(6.5)(37)(37) = 625^{1-K}$

CASE II (1 Support + Ext.)



$M_A = 5.67(3.25)(5.67).5 = 52.0^{1-K}$

$M_B = 1112 - 26 = 1086^{1-K}$

$V_{A\ CANT} = 37^{K}$

$V_{AB} = 90.2 + \frac{78}{37} = 92.3^{K}$

$V_A = 37 + 92.3 = 129.3^{K}$

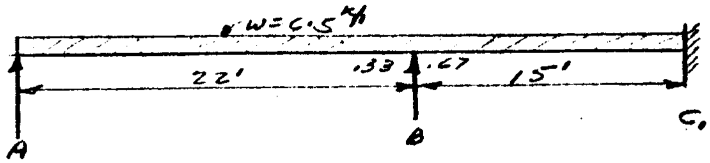
$V_B = 150.2 - 2.1 = 148.1^{K}$

Case III (2 Supports - No Ext.)

Dist. Factors:

BC. $\frac{4}{15} = .267 \div .403 = .67$

BA. $\frac{3}{22} = \frac{.136}{.403} \div .403 = .33$



FEM:

AB & BA: $\frac{1}{12}(6.5)(22)^2 = 262^{'k}$

BC & CB: $\frac{1}{12}(6.5)(15)^2 = 122^{'-k}$

$V_{BA} = 11(6.5) + \frac{318}{22} = 86.0^k$ (14.5)

$V_{BC} = 7.5(6.5) + \frac{290}{15} = 68.1$ (19.3)

$V_B = 154.1^k$

A	BA	BC	CB
+262	-262	+122	-122
-262	+47	+93	0
+24	-131	0	+47
-24	+44	+87	0
+22	-12	0	+43
-22	+4	+8	0
+2	-11	0	+4
-2	+3	+8	0
0	-318	+318	-28'

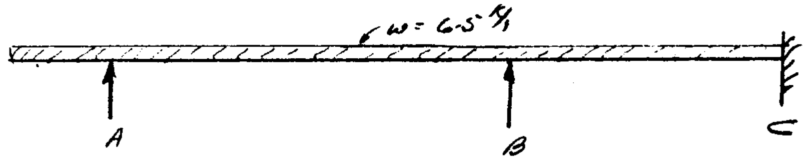
Case II - (2 supports)

M_A (cant.) $= 52.0^{'-k}$

V_A cant $= 5.67(6.5) = 36.8$

$V_{AB} = 11(6.5) + \frac{267}{22} = 60.3$

$V_A = 97.1^k$



$V_{BA} = 82.7^k$

$V_{BC} = 7.5(6.5) + \frac{266}{15} = 66.4^k$

$V_B = 149.1^k$

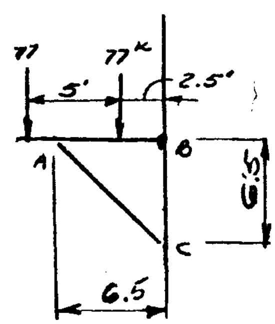
$V_C = 31.0^k$

Cant.	A	BA (.33)	BC (.67)	CB
-52	+262	-262	+122	-122
	-210	+47	+93	0
	+24	-105	0	+47
	-24	+35	+70	0
	+18	-12	0	+35
	-18	+4	+8	0
		-9	0	+4
		+3	+6	0
				+3
-52	+52'-k	249'-k		-33

Use Two Supports:

ΣM @ B:

$V_A = \frac{77 \times 10}{6.5} = 118.5$



$P_{AC} = 1.414(118.5) = 168^k$

$l = 6.5(1.414) = 9.2'$

Use 8WF40 for A.C.

Beam AB.

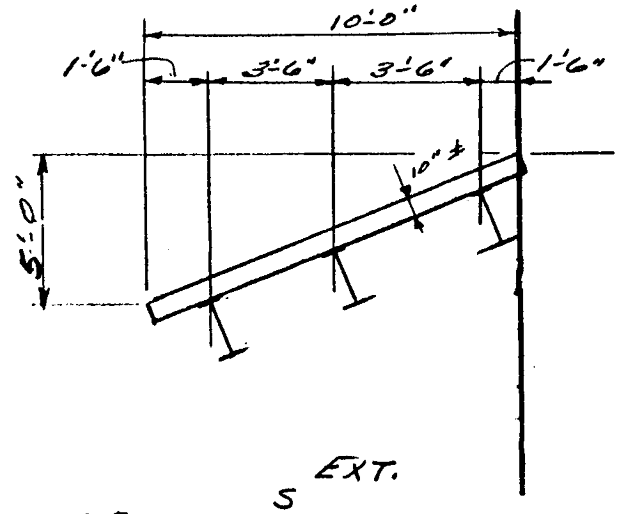
$M_a = 1(77) = 77^{'-k}$

$+M = (118.5 - 77)(4) - 77 = 89^{'-k}$

Use 12WF45

SHIELD OVER SWING ARMS:

Assume Blast load = 10#/□" = 1.44 K/□'
Horz. Width = 10'-0"
Rise = 5'-0"



Assume Heavy Decking w/topping suitable for high temp.

$w = 1.44 \times 3.5 = 5.04$ K/'

Assume beam are laterally supported.

Max Mom $= \frac{1}{8}(22)^2(5.04)$ K/' $= 304$ '-K

Assume f all = 20,000 × 1.33 = 26,667

$S_{req'd} = \frac{304 \times 12}{26.667} = 137''^3$ → 21WF68, 18WF77	A-7	–	127	21WF62, 18WF70
$\frac{26.67}{29.2}(137) = 126$ → 21WF62, 18WF70	A36	–	117	18WF64, 16WF71
$\frac{26.67}{33.3}(137) = 110$ → 18WF64, 16WF71	A440	–	102	16WF64, 18WF60

(S column heading; EXT.)

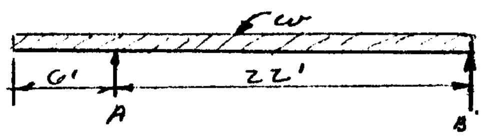
FIND REACTION @ A:

V_H cont. = 6 w:

$M_A = 18w$

$V_{AB} = 11w + \frac{18w}{22} = 11.82w$

$V_A = 17.82w$



w_1 = int beam = 3.5(1.44) = 5.04 K/' + .2 = 5.24 K/'　　$V_A = 93.5^K$

w_2 = Ext. beam = 3.25(1.44) = 4.68 + .2 = 4.88 K/'　　$V_A = 87.2^K$

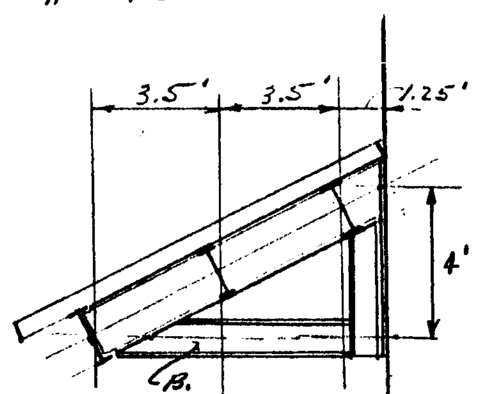
BRACKET:

Member B:

$P_B = [9.5(87.2) + 93.5(4.75)]\frac{1}{4} = 318^K$

$\ell = 6.5'$

Use → 8WF67



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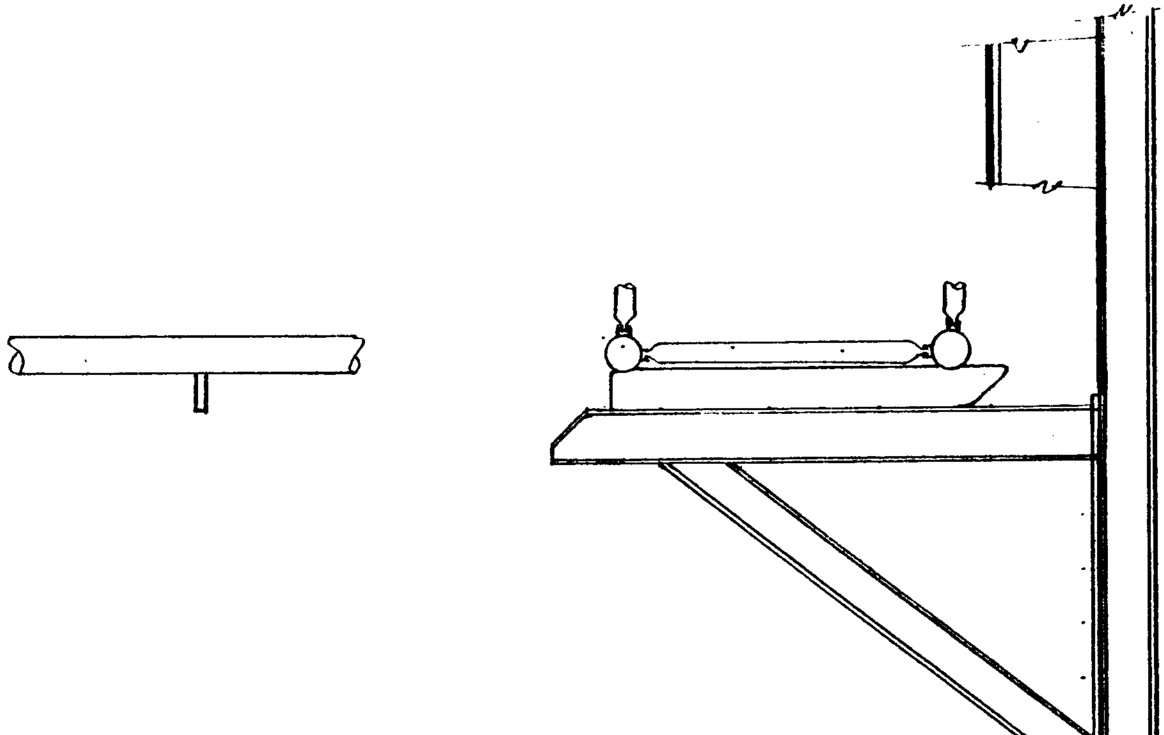
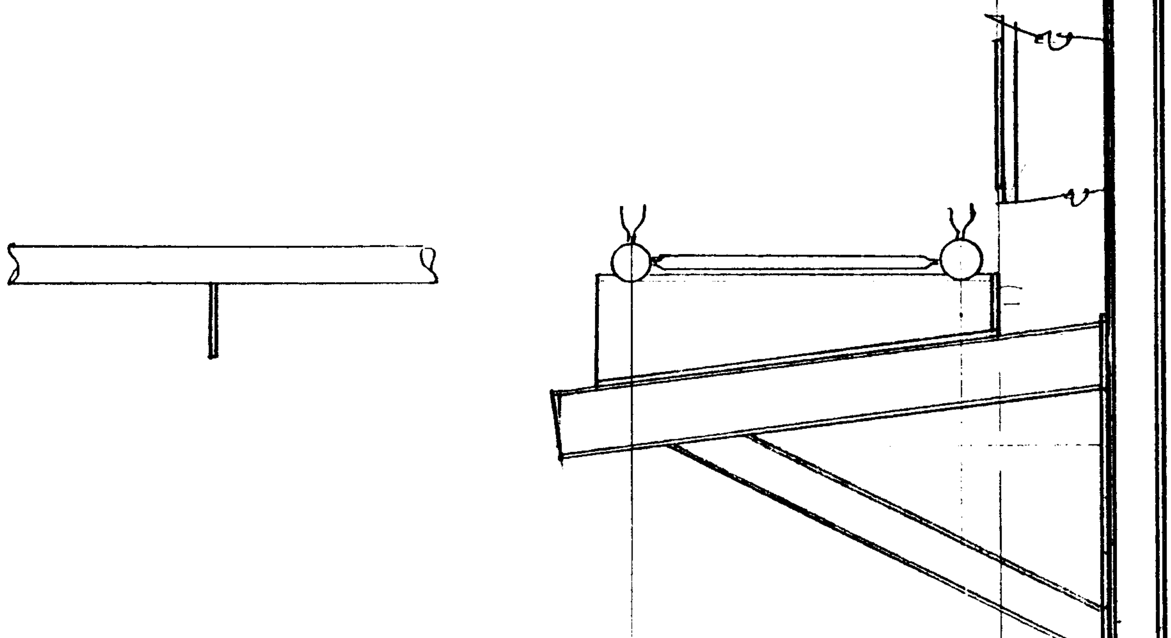


HORIZONTAL ARM SUPPORTS



SLOPED OR RAMPED ARM SUPPORTS

PREPARED BY R.L. **BROWN** ENGINEERING COMPANY, INC. PAGE 6
CHECKED BY Surf REPORT NO.
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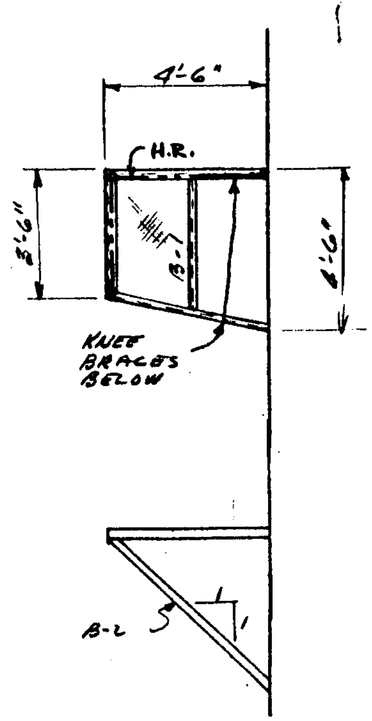
ACCESS PLATFORMS – ACCESS ARMS:

B-1: USE L.L. = 100#/□' D.L. = 10#/□'
$w = 2.25(110) = 248^{\#}/'$
$M = \frac{1}{8}(248)(4)^2 = 496$ 1-#
$f_s = 20{,}000^{\#}/\square'$ $S_{req'd} = \frac{496(12)}{20{,}000} = .3$
Use 3[@4.1#/'



B-2: AREA PLAT. = 4×4.5 = 18□' W = 18(110) = 1980# say 2k
$P = [2.25(2) \div 4.5]\,1.414 = 1.4^k$
$l = 6.3' = 76"$ $r_{min} = \frac{76}{200} = .38$
Use 3[@4.1 $f_{all} = 3.35^k/\square"$ $A = 1.19\square"$

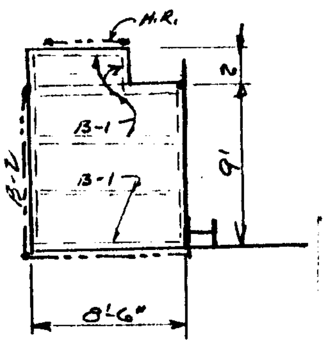
QUANTITIES:
EXPANDED GRATING = 18 SF.
ALUM. H.R = 3.5+4.5 = 8 L.F.
[= 25(4.1) = 102.5(1.2) = 123#

~~COST:~~
~~GRATING: 18 SF @ \$2.00 = \$36~~
~~[: 123# @ \$0.22 = \$27~~
~~H.R. 8 @ \$3.00 = \$24~~
~~\$87~~

see Cost Summary p. 4.

ACCESS PLATFORM – SERVICE ARM

PLAN B:



B-1 L.L. = 100#/□' D.L. = 10#/□' l = 8.5' s = 3' w = 330#/'
ASSUME LATERALLY SUPPORTED
$M = \frac{1}{8}(8.5)^2(330) = 2970$ 1-#
$S_{req'd} = \frac{2970 \times 12}{20{,}000} = 1.8$ $R = 330 \times 4.25 = 1.4^k$
Use [4×1 5/8 @ 5.4# l = 41.5'

B-2: $P = 1.4^k$ $M = 1.4 \times 3 = 4.2^{1\text{-}k}$
$S_{req'd} = \frac{4.2 \times 12}{20} = 2.52"^3$
Use [5×1 3/4 × 6.7# l = 20'

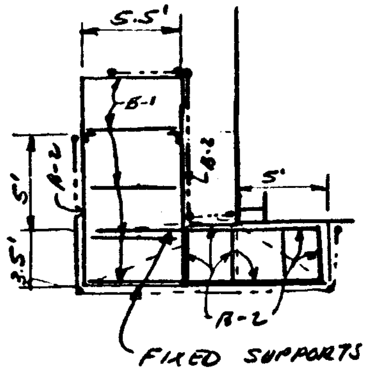
KNEE BRACE:
$P = [1.4 + 1.7]\,1.414 = 3^k$ $l = 8.5(1.414) = 11.9'$
$r_{min} = \frac{11.9 \times 12}{200} = .72$ $f_{all} = 3.35^k/\square" @ \frac{l}{r} = 200$
Use L4×4×1/4" @ 6.6#/'

QUANTITIES: Steel: [41.5(5.4) + 20(6.7) + 11.9(6.6)]1.15 = 504#
GRATING: 9(8.5) + 2(5.5) = 88 SF.
H.R.: 8.5 + 9 + 3.5 = 21 LF.

COST: STEEL. 504 × .22 = \$111.00
88 × 2.00 = \$176.00 TOT \$350
21 × 3.00 = \$63.00

SEE COST SUMMARY P. 3

Access Platform – Plan A



B-1: $w = 330^{\#/'}$ $l = 5.5'$ $M = \frac{1}{8}(330)(5.5)^2 = 1250^{'-\#}$

Assume Laterally Supported $R = 908^{\#}$ say 1^k

$S_{req'd} = \frac{1250 \times 12}{20{,}000} = .75^{''3}$

Use: [3x1½ @ 4.1# $l = 27.5' = 113$ #

B-2: $l_{max} = 5'$-0" Use Conc. Load @ Center of Span:

$P = 1^k$ $M = \frac{1(5)}{4} = 1.25^{'-k}$

Use 3x1½ @ 4.1# $l = 53' = 217$ #

For fixed supports use [5x1¾ @ 6.7# $l = 27' = 181$ #

For knee braces use L 4x4x¼" @ 6.6# $l = 44' = 290$ #

Grating: 5.5x11.5 + 8x3.5 = 92 SF

H.R.: 8.5+13.5+3+3.5+8 = 36.5 L.F

Costs:

~~H.R.: 36.5 x \$3 = \$109.50 = \$110~~

~~Steel: 921 @ \$0.22 = \$203.00~~

~~Grating: 64 x \$2.00 = \$128.00~~

~~Tot. = \$441~~

Ave. Cost = \$400

See cost summary p.3.

Latchback: (See cost summary p.4)

2 Microswitches @ = See Elec. Est.

2 Pins & Actuators @ = See Mech. Est.

2 Rubber Pads @ 3 =

4 SF of ¾" Alum PL x 2 @ =

Alum. Skid & Brackets (est.) =

Alux. Arm. Support: (See cost summary p.4)

Wt. = 8(45) = 360#

= 9(40) = 360

Tot = 720# x 1.10 (conn.) = 800#

COST SUMMARY:

ACCESS PLATFORM: PLAN A : SERVICE ARM

Material:

1¼"φ x ⅛" wall pipe (alum)	68' @ .52#/' = 36	# @ $1.00/#	= $36.00
Mild Steel (A7)	921# @ $.15		= $138.00
Expanded metal flooring (alum.)	92 SF @ $1.30		= $120.00
			$294.00

Labor Cost:

Cat.	Man-Hours	Ave-Rate	Total Lab Cost
Machine Shop	—	$5.85	—
Fab.-Weld	25	$6.00	$150.00
Painting	3	$5.30	16.00
Inspection	1	$4.90	5.00
Quality Control	1	$6.50	6.00
			$177.00

Σ: MATERIAL COST - $294.00
LABOR COST - 177.00
10% PROFIT - 47.00
$518.00

ACCESS PLATFORM : PLAN B : SERVICE ARM :

Material:

1¼"φ x ⅛" wall alum pipe:	38.5' @ .52#/' = 20	# @ $1.00/#	= $20.00
Mild steel A-7	504# @ $.15/#		= $76.00
Expanded metal flooring (alum)	88 SF @ $1.30		= $114.00
			$210.00

Labor Cost:

Cat.	Man-Hours	Ave Rate	Total Labor Cost
Fab-Weld	20	$6.00	120.00
Painting	3	5.30	16.00
Inspection	1	4.90	5.00
Quality Control	1	6.50	6.00
			$147.00

Σ MATERIAL COST $210.00
LABOR COST 147.00
10% PROFIT 36.00
$393.00

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Cost. Summary Cont.

Access Platform - Access Arms

Material:

H.R. $1\frac{1}{2}$"φ x $\frac{1}{8}$" wall (alum.) 18.5 LF @ .52#/1 = 10# @ $1.00	=	$10.00
Steel A-7 123# @ $0.15/#	=	$19.00
Grating - Expanded alum: 18 SF @ $1.30	=	$24.00
		$53.00

Labor Cost

Cat.	Man-Hours	Ave-Rate	Total Labor Cost
Fab-Weld	10	$6.00	60.00
Painting	2	5.30	11.00
Inspection	1	4.90	5.00
Quality Control	1	6.50	6.00
			82.00

Σ Material Cost $53.00
Labor Cost 82.00
10% Profit 14.00
$149.00

Aux Arm Support:

Material:
A-7 steel. 800# @ $.15 = $120

Labor:

Fab-Weld:	8 hours	@ 6.00	=	48.00
Painting	3 hours	@ $5.30	=	16.00
Inspection	1 hour	@ 4.90	=	5.00
Quality Control	1 hour	@ 6.00	=	6.00
				75.00

Σ. Material = $120.00
Labor = 75.00
10% Profit = 20
$215.00

Latch-Back: For Micro-switches & Actuator-Pins see Elect & Mech. estimates.

Material:

2 Rubber Bumper Pads @ $5.00 each	=	$10.00
Skid: Almag 35 60# @ $.38	=	23.00
Latch-back " 95# @ .38	=	36.00
		$69.00

Labor:

Cat.	Man-Hours	Ave-Rate	Total-Labor Cost
Machine Shop	6	$5.85	35.00
Fab.-Weld	14	6.00	84.00
Inspection	2	4.90	10.00
Quality Control	1	6.50	6.00
			$135.00

Σ Mat. + Labor + 10% Profit = 69 + 135 + 21 = $225

COST ESTIMATE
HYDRAULIC / PNEUMATIC SYSTEMS

PRE-LAUNCH SERVICE ARM

HYD. ROTARY ACTUATORS		
BASIC UNITS	5,600	
BRGS., CAMS, & MISC. HDW.	400	
LABOR	2,800	
		8,800
PNEUMATIC ACTUATORS		
BASIC UNITS	1,350	
MOUNTING & MOD. MAT'LS	730	
LABOR	5,400	
		7,500
HYD. PNEUMATIC CIRCUITS		
ACCUMULATORS	1,880	
VALVES	7,590	
REGULATORS, GAGES, ETC.	1,740	
TUBING & HDW.	5,110	
LABOR	13,100	
		29,400
TOTAL		45,700

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COST ESTIMATE HYDRAULIC/PNEUMATIC SYSTEMS

IN FLIGHT SERVICE ARM

HYD. ROTARY ACTUATORS		
BASIC UNITS	5,600	
BRGS., CAMS & MISC. HDW.	400	
LABOR	2,800	
		8,800
PNEUMATIC ACTUATORS		
BASIC UNITS	910	
MOUNTING & MOD. MAT'LS	610	
LABOR	4,600	
		6,100
HYD & PNEUMATIC CIRCUITS		
ACCUMULATORS	1,880	
VALVES	5,880	
REGULATORS, GAGES, ETC.	1,740	
TUBING & HDW.	4,690	
LABOR	12,070	
		26,200
	TOTAL	41,100

COST ESTIMATE HYDRAULIC/PNEUMATIC SYSTEMS

ACCESS ARM

HYD. ROTARY ACTUATORS		
BASIC UNITS	16,000	
BRGS, CAMS, & MISC. HDW.	600	
LABOR	4,200	
		20,800
PNEUMATIC ACTUATORS		
BASIC UNITS	240	
MOUNTING & MOD. MATL'S	120	
LABOR	1,200	
		1,600
HYD & PNEUMATIC CIRCUITS		
ACCUMULATORS	2,860	
VALVES	6,170	
REGULATORS, GAGES, ETC	1,110	
TUBING & HDW.	4,140	
LABOR	10,540	
		24,800
TOTAL		47,200

FOR A PAIR
2 × 47,200 = 94,400

COST ESTIMATE HYDRAULIC/PNEUMATIC SYSTEMS

UMBILICAL TOWER SUPPLY SYSTEM

HYD. CART, RESERVOIR, & TUBING INSTALLATION

BASIC CART	7,000	
RAW MAT'LS	600	
TUBING, FITTINGS & HDW.	3,830	
LABOR	5,250	
		16,700

PNEUMATIC COMPRESSOR & TUBING INSTALLATION

BASIC COMPRESSOR	12,000	
RAW MAT'LS	200	
TUBING, FITTINGS & HDW.	1,600	
LABOR	2,100	
		15,900
TOTAL		32,600

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COST ESTIMATE HYDRAULIC/PNEUMATIC SYSTEMS

TOTAL SYSTEM

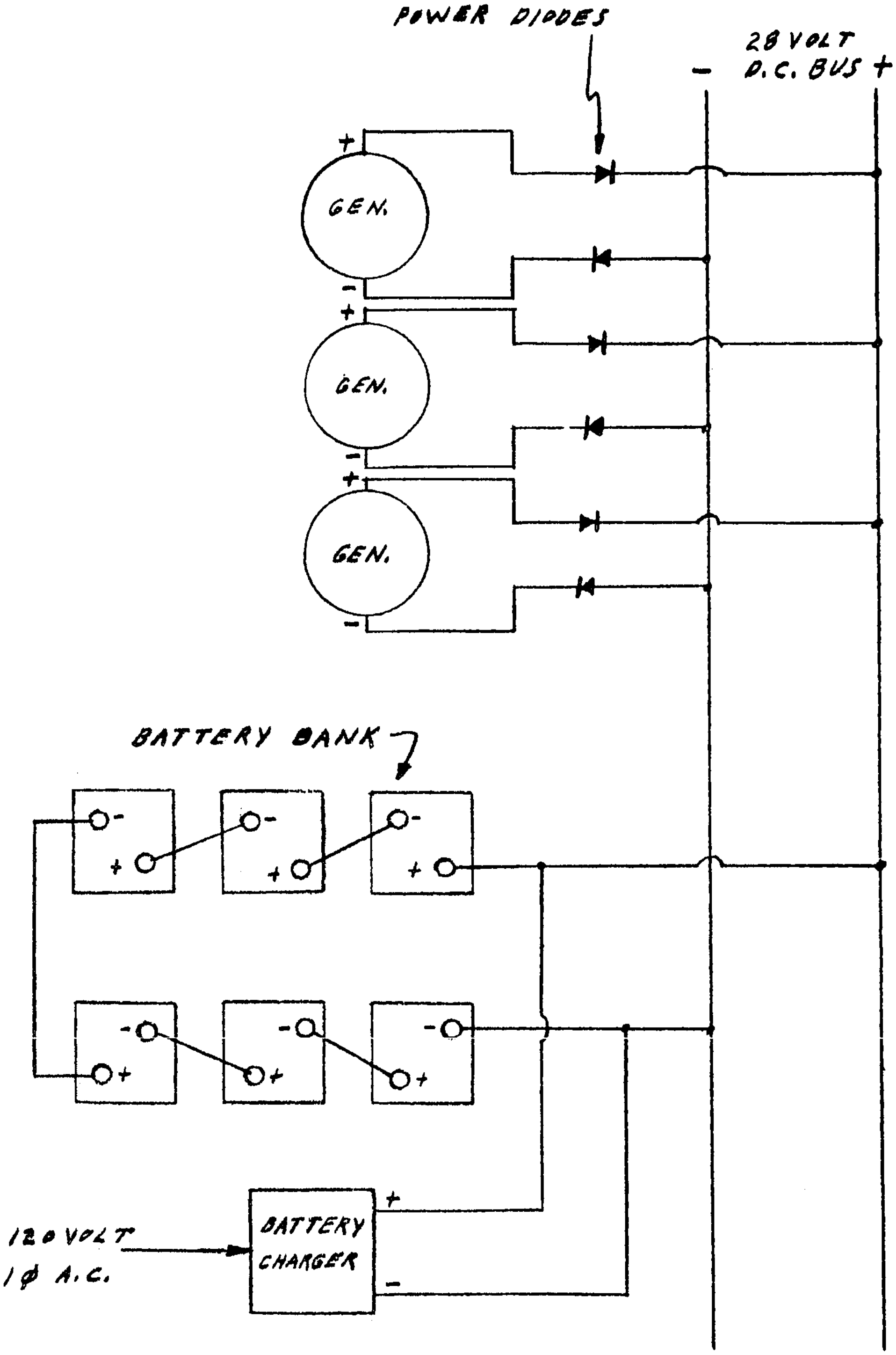
IN-FLIGHT SERVICE ARMS	
2 @ 41,100	82,200
PRE-LAUNCH SERVICE ARMS	
5 @ 45,700	228,500
ACCESS ARMS	
4 @ 47,200	188,800
TOWER SUPPLY SYSTEM	
1 @ 32,600	32,600
TOTAL	531,100

6

TEST SITE
FACILITIES

SITE PREPARATION	213,000.
FUEL TANK AREA	54,000.
BUILDINGS	72,000.
CONTROL CONSOLE	20,000.
INSTRUMENTATION	150,000.
AREA B	700,000.
AREA A	146,000.
	1,355,000.

BLOCK DIAGRAM OF 28 VOLT D.C. POWER SOURCE



BATTERY SIZE DETERMINATION

EMERGENCY LIGHTING D. C. AMPS — 120 AMPS TO 300 AMPS

TOTAL SOLENOID OPERATED VALVES THAT COULD BE ENERGIZED SIMULTANEOUSLY — 96

AVERAGE CURRENT PER SOLENOID — 2 AMPS

CONTROL RELAY & INDICATOR LIGHT CURRENT — 120 X .05 = 6 AMPS

TOTAL CONTROL, INDICATION & ACTUATE CURRENT —

(3 HOURS) $I_T = 120 + (96 \times 2) + 6 = 318$ AMPS

(1 HOUR) $I_T = 300 + 192 + 6 = 498$ AMPS

NO. OF CELLS IN BATTERY BANK —

$$\frac{\text{BATT. TERMINAL VOLTAGE}}{\text{VOLTS PER CELL}} = \frac{26}{2.1} = 12.4$$

USE 13 CELLS — TERM. VOLTAGE = 13 X 2.1 = 27.3 VOLTS

$$\frac{\text{REQUIRED AMPS (3 HOURS)}}{\text{AMPS PER POSITIVE PLATE (3 HOUR DISCHARGE)}} = \frac{318}{100} = 3.18 \text{ POSITIVE PLATES}$$

(GOULD TYPE EC-21)

$$\frac{\text{REQUIRED AMPS (1 HOUR)}}{\text{AMPS PER POSITIVE PLATE (1 HOUR DISCHARGE)}} = \frac{498}{200} = 2.49 \text{ POSITIVE PLATES}$$

(GOULD TYPE EC-21)

5.67 TOTAL POSITIVE PLATES

FOR THIS APPLICATION USE A 6 POSITIVE AND 7 NEGATIVE PLATE CELL GOULD STATIONARY CELL TYPE EC-21 OR EQUIVALENT MEETS THE REQUIREMENTS SATISFACTORILY

AMPERE-HOUR CAPACITY (8 HR. RATE OF DISCHARGE) = 400

RELAY VOLTAGE DROP CALCULATIONS

Cable length from Blockhouse Control & Indication Panel to Umbilical Tower — 10,000 ft.

Cable size — No. 18 AWG Type — Stranded Copper

Cable resistance — 6.5 ohms per 1000 ft.

Typical inter-posing relay — 28 Volt D.C.

Coil resistance — 550 ohms

Maximum required operating voltage — 20 Volts D.C.

Lowest Voltage condition due to D.C. Generator failure — 24 Volts D.C.
(Battery voltage only)
(with low state of charge)

Voltage appearing across relay coil —

$$V = R_R / R_R + R_L \times E \qquad R_R = 550 \text{ ohms}$$

$$R_L = 10{,}000 \times 6.5/_{1000} = 65 \text{ ohms}$$

$$V = \frac{550}{550 + 65} \times 24$$

V = 21.46 Volts D.C. across relay coil

Normal Voltage condition — 28 Volts D.C. (Generators operating and Batteries having normal state of charge)

Voltage appearing across relay coil —

$$V = R_R / R_R + R_L \times E$$

$$V = \frac{550}{550 + 65} \times 28$$

V = 25.04 Volts D.C. across relay coil

These calculations are based on the Negative side of the low-current control lines being picked up at the Relay location, thereby using the Facility Negative for a return.

The following calculations show the feasability of using No. 20 AWG Stranded Copper cable :

Low Voltage Condition — 24 Volts D.C.

$$V = R_R / R_R + R_L \times E \qquad R_R = 550 \text{ ohms}$$

$$R_L = 10{,}000 \times \frac{10.4}{1000} = 104 \text{ ohms}$$

$$V = \frac{550}{550 + 104} \times 24$$

V = 20.16 Volts D.C. across relay coil

UMBILICAL TOWER PLATFORM LIGHTING

TYPICAL PLATFORM AREA TO BE ILLUMINATED — 2000 SQ. FT.

REQUIRED LEVEL OF ILLUMINATION — 20 FT-CANDLES

TOTAL LUMENS REQUIRED — $\frac{20 \text{ FT-CANDLES} \times 2000}{.75} = 53,333$

SELECT HEAVY DUTY FLOODLIGHT

WITH WIDE BEAM REFLECTOR & WIDE BEAM LENS (500 WATT LAMP)

BEAM LUMENS — 5,290 ← LUMENS SUPPLIED BY CHOSEN FIXTURE

BEAM SPREAD — HOR. 143° 500 WATT LAMP

VERT. 48.5°

USE 12 LAMPS PER PLATFORM

LUMENS PER LAMP — $\frac{53,333}{12} = 4,444$ ← REQUIRED LUMENS PER LAMP

TOTAL PLATFORM FIXTURES — 8 X 12 = 96

ACCESS ARM LIGHTING

AREA TO BE ILLUMINATED — 5' X 120' + 5' X 50' = 850 SQ. FT.

LEVEL OF ILLUMINATION — 20 FT. CANDLES

TOTAL LUMENS REQUIRED — $\frac{20 \times 850}{.75} = 22,666$

SELECT HAZARDOUS AREA FLOODLIGHT WITH WIDE BEAM REFLECTOR AND PLAIN LENS (300 WATT LAMP)

BEAM SPREAD — HOR. 80° BEAM LUMENS — 1626 ← SUPPLIED LUMENS

VERT. 83.1°

USE 16 LAMPS

LUMENS PER LAMP — $\frac{22,666}{16} = 1417$ ← REQUIRED LUMENS

SERVICE ARM LIGHTING

AREA ON ARM TO BE ILLUMINATED — 5' X 45' = 225 SQ. FT.

AREA ON VEHICLE TO BE ILLUMINATED — 10' X 10' = 100 SQ. FT.

LEVEL OF ILLUMINATION — 20 FT.-CANDLES

TOTAL LUMENS REQUIRED — 20 X 325 = 6500

SELECT HAZARDOUS AREA FLOODLIGHT WITH NORMAL BEAM REFLECTOR AND PLAIN LENS (200 WATT LAMP) BEAM SPREAD — HOR. 72°

VERT. 58°

BEAM LUMENS — 962 ← SUPPLIED LUMENS

USE 7 LAMPS

LUMENS PER LAMP — $\frac{6500}{7} = 929$ ← REQUIRED LUMENS

TOTAL SERVICE ARM FIXTURES — 5 X 7 = 56

ELECTRICAL SYSTEM

COST ESTIMATE

ONE ACCESS ARM

ITEM	NO.	UNIT COST	TOTAL COST
LIGHT FIXTURES	8	260.00	$2,080.00
3/4" CONDUIT	100 ft.	.20	20.00
CONDULETS	12	3.00	36.00
SOUND POWER EQUIPMENT	1	1000.00	1,000.00
CABLE, LIGHTING	100 ft	.20	20.00
SWITCHES	12	150.00	1,800.00
CABLE, COMMUNICATIONS	100 ft	.80	80.00
CABLE, CONTROL	1000 ft	1.00	1,000.00
TEST BOX	1	1,000.00	1,000.00
MISCELLANEOUS	—	—	1,000.00
			$8,036.00
LABOR	640 M-H	6.00	$3,840.00
			$11,876.00
		Say	11,900.

ELECTRICAL SYSTEM

COST ESTIMATE
ONE IN-FLIGHT SERVICE ARM

ITEM	NO.	UNIT COST	TOTAL COST
LIGHT FIXTURES	6	260.00	$1560.00
3/4" CONDUIT	60 ft.	.20	12.00
CONDULETS	9	3.00	27.00
CABLE, LIGHTING	60 ft	.20	12.00
CABLE, CONTROL	800	1.00	800.00
SWITCHES	10	150.00	1500.00
TEST BOX	1	1000.00	1000.00
MISCELLANEOUS	—	—	1500.00
			$6,411.00
LABOR	560 M-H	6.00	$3,360.00
			$9,771.00
		Say	9,800.

ELECTRICAL SYSTEM

COST ESTIMATE

ONE PRE-LAUNCH SERVICE ARM

ITEM	NO.	UNIT COST	TOTAL COST
LIGHT FIXTURES	6	260.00	$1560.00
3/4" CONDUIT	60 ft	.20	12.00
CONDULETS	9	3.00	27.00
CABLE, LIGHTING	60 ft	.20	12.00
CABLE, CONTROL	800 ft	1.00	800.00
SWITCHES	40	150.00	6,000.00
TEST BOX	1	1500.00	1,500.00
MISCELLANEOUS	—	—	1,500.00
			$11,411.00
LABOR	760 M-H	6.00	$4,560.00
			$15,971.00
		Say	16,000.

ELECTRICAL SYSTEM

COST ESTIMATE

TOWER

ITEM	NO.	UNIT COST	TOTAL COST
LIGHT FIXTURES	120	170.00	$20,400.00
CABLE TRAYS	4000 ft	10.00	40,000.
CONDULETS	500	5.00	2,500.00
CONVENIENCE OUTLETS	80	5.60	448.00
SOUND POWER EQUIPMENT	1 LOT	8,000.00	8,000.00
CABLE, LIGHTING & POWER	20,000 ft	.40	8,000.00
CABLE, COMMUNICATIONS	8,000	.80	6,400.00
CABLE, CONTROL	30,000	1.00	30,000.00
POWER PANEL (WITH CIRCUIT BREAKERS)	1	4,000	4,000.00
CONTROL JUNCTION BOXES	9	1,500	13,500.00
MISCELLANEOUS	—	—	30,000.00
			$163,248.
LABOR	10,000 M-H	6.00	$60,000.00
			$223,248.
		say	223,300.

ELECTRICAL SYSTEM

COST ESTIMATE

AGC AREA

ITEM	NO.	UNIT COST	TOTAL COST
LIGHTING FIXTURES	20	170.00	$3,400.00
CONDUIT	3,000	2.00	6,000.00
CONDULETS	40	5.00	200.00
CONVENIENCE OUTLETS	15	5.60	84.00
SOUND POWER EQUIPMENT	1	1,000.00	1,000.00
CABLE, LIGHTING & POWER	600 ft.	.40	240.00
CABLE, COMMUNICATIONS	300 ft.	.80	240.00 ~~24.00~~
CABLE, CONTROL	2,000 ft	1.00	2,000.00
POWER PANEL (WITH CIRCUIT BREAKERS)	1	1,000.00	1,000.00
CONTROL JUNCTION BOX	1	1,000.00	1,000.00
CONTROL RELAY PANEL	1	1,000.00	1,000.00
CONTROL RELAYS	300	20.00	6,000.00
MISCELLANEOUS	—	—	3,000.00
			$25,164.0
LABOR	1500 M-H	6.00	$9,000.00
			$34,164.0
		Say	34,200.

ELECTRICAL SYSTEM

COST ESTIMATE
LAUNCH CONTROL CENTER

ITEM	NO.	UNIT COST	TOTAL COST
CONTROL PANEL	1	1,000.00	$1,000.00
INDICATOR SWITCHES	60	12.50	750.00
INDICATOR LIGHTS	450	7.00	3,150.00
CABLE, CONTROL	1,000 ft	1.00	1,000.00
RELAYS	20	20.00	400.00
TIMERS	2	500.00	1,000.00
SOUND POWER EQUIPMENT	1	2,000.00	2,000.00
CONDUIT	3,000	2.00	6,000.00
CONDULETS	100	5.00	500.00
CONVENIENCE OUTLETS	25	5.60	140.00
CABLE, LIGHTING & POWER	2,000	.40	800.00
CABLE, COMMUNICATIONS	600	.80	480.00
CONTROL JUNCTION BOX	1	1,000.00	1,000.00
POWER PANEL (WITH CIRCUIT BREAKERS)	1	1,200.00	1,200.00
MISCELLANEOUS	—	—	2,500.00
			$21,920.00
LABOR	1500 M-H	6.00	$9,000.00
			$30,920.00
		say	31,000.

CENTER OF PERCUSSION (S-II AFT SERVICE ARM)

$$q = \frac{I_m}{m\bar{r}}$$

$$\bar{r} = \frac{1}{10{,}575\ \text{LB}}\left[(2825\ \text{LB})(38.75\ \text{FT}) + (7750\ \text{LB})(19.37\ \text{FT})\right]$$

$$\bar{r} = 24.55\ \text{FT} = 295\ \text{IN.}$$

SO

$$q = \frac{(3.16\times10^6\ \text{IN-LB-SEC}^2)(32.2\ \text{FT/SEC}^2)}{(10{,}575\ \text{LB})(295\ \text{IN})}$$

$$q = 32.62\ \text{FT} \simeq \boxed{390\ \text{IN}}$$

CABLE TENSION

$$T \simeq \left[\int_0^{\Phi} \frac{d\phi}{\sqrt{\sin\phi}}\right]^2 \left[\frac{\sqrt{n^2+1}}{2n}\right]\left[\frac{I_m}{r\,t^2}\right]$$

SEE "CONVERTING LINEAR TO ROTARY MOTION" BY D.P. HANLEY - "MACHINE DESIGN" DATA SHEET MARCH 6, 1958 -

$$n = L/r = \frac{390\ \text{IN}}{390\ \text{IN}} = 1$$

$$\frac{\sqrt{n^2+1}}{2n} = \frac{1}{\sqrt{2}} = .707$$

SECONDARY RETRACTION SYSTEM

$\Phi = 36.5°$

$$\therefore \int_0^{\Phi} \frac{d\phi}{\sqrt{\sin\phi}} = 1.6$$

$I_m = 3.16 \times 10^6$ IN-LB-SEC^2

$r = 390$ IN.

$t = 3.0$ SEC

$$T \simeq \frac{(1.6)^2(.707)(3.16 \times 10^6 \text{ IN-LB-SEC}^2)}{(390 \text{ IN})(3.0 \text{ SEC})^2} = \boxed{2190 \text{ LBS}}$$

ACTUATOR FORCE

$$F = \frac{8T}{E}$$

ASSUME EFFICIENCY OF SINGLE PULLEY TO BE .95

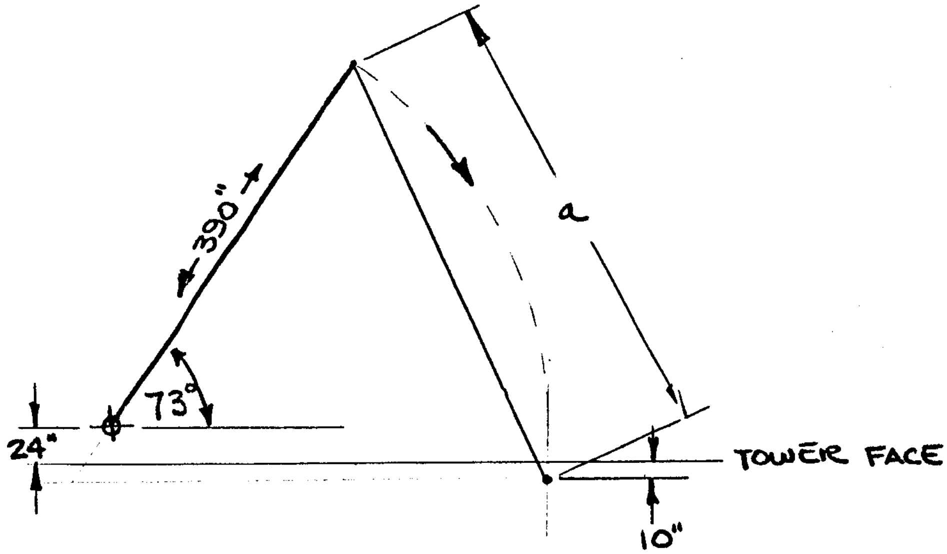
SEE "MARK'S MECH. ENGR. HANDBOOK", 6TH EDITION, PP 3-52

TOTAL EFFICIENCY $\simeq (.95)^8 \simeq .65$

$$\therefore F = \frac{(8)(2190 \text{ LB})}{.65} \simeq \boxed{27{,}000 \text{ LB}}$$

SECONDARY RETRACTION SYSTEM

CABLE TRAVEL



$$a = 2\left(390 + \frac{34}{\sin 73^\circ}\right)\sin 36.5^\circ \simeq 506 \text{ IN}$$

$$\text{TOTAL CABLE TRAVEL} = 506 - 34 = \boxed{472 \text{ IN}}$$

ACTUATOR STROKE

$$S = \frac{\text{CABLE TRAVEL}}{8} = \frac{472 \text{ IN}}{8} = 59 \text{ IN} \simeq \boxed{5 \text{ FT}}$$

APPENDIX C

The information found in this Appendix was not incorporated in main portion of the text because it was received too late.

CURVES FOR C-5 VEHICLE CHARACTERISTICS AND DATA

(From M-P&VE-P)

a. DRIFT CURVES

Figures 1 and 2 show the drift of the vehicle toward the tower.

Figure 3 shows the normal force coefficient.

b. VEHICLE DEFLECTION

Figure 4 shows the lateral deflection caused by 99-percent winds, as the vehicle is released to a flight or free beam condition.

Figures 5 through 10 show sway of the vehicle caused by wind.

Figure 11 is a plot of lateral deflections due to a one-degree fahrenheit differential solar warpage. The maximum expected temperature differential due to solar heating is determined to be 53 degrees fahrenheit.

Figures 12 and 13 show plots for vertical deflection due to load crush and temperature shrinkage.

c. VEHICLE LIFT-OFF

Figure 14 shows the vehicle lift-off rate.

d. ACOUSTICS

Curves of acoustic pressures and frequences are shown in figures 15 through 20.

e. IMPINGEMENT PRESSURES AND TEMPERATURE

Figures 21 through 26 show impingement pressures and temperatures.

No satisfactory approach is available to predict either pressures or temperature which the tower will realize as a result of C-5 engine jet impingement. Therefore, it was necessary to combine theory with applicable experimental data already available in predicting these effects. The heating rates which were used are based on measurements of heat transfer to a body exposed to Jupiter engine exhaust, with analytical correction for body shape and size. nozzle exit temperature, and distance between the body and nozzle exit. The temperature and pressure decay as a function of distance behind the nozzle exit was based on experimental data, in conjunction with theoretical prediction of the jet shock and pressure. The temperatures shown are predicted to be the maximum which will occur anywhere on the tower proper. Tower platforms are shielded from the jet blast by other platforms as the nozzles pass above them, and are at greater distances from the nozzle when impingement occurs. The vertical beams experience lower convective heat transfer coefficients and are massive, than the stagnation point values which the platforms experience. According to preliminary information from LOD, typical dimensions for the beams near the top of the platform are 1-1/4-inch thick flanges and 3/4-inch thick web. Typical dimensions for lower beams are 4 and 2 inches, respectively for flange and web thicknesses. The horizontal I beams are less influenced by jet heating than the vertical members, due to the

shielding they receive from the platforms as the nozzles move above.

The maximum predicted pressure, which will be experienced by localized areas on platforms, as the nozzles move above them is 140 psia. The top platform will experience this pressure over most of its surface, as all five nozzles pass above it.

The maximum pressure acting on the umbilical arms is predicted to be 140 psia. No temperatures on umbilical arm components have been predicted, however, some comments can be made. The umbilical arms, like the top platform, experience high convective heating. The arm structure is composed of aluminum (6061-T6) tubing with outside diameters and wall thicknesses of 3 X 3/8 inches, 3 X 5/16 inches, and 2-1/2 X 3/16 inches. A comparison of the thermal environment and the mass of arm structural members with those of the platform, which was analyzed, indicates that arm structural component temperatures will approach or exceed the melting point of aluminum (1200° F).

No purely theoretical method exists for accurately determining the temperature and pressure distribution in a jet wake as a function of distance, considering the effects of nozzle exit pressure temperature, velocity gradients, mixing at the jet wake boundaries, complex shapes within the jet wake, interaction with surfaces, etc. Testing is required for design information which can be used with a high degree of confidence. On this basis, it is recommended that the estimates

presented here be considered preliminary and that steps be taken to obtain test data as soon as possible. Pressure and temperature measurements on the launcher platform during the upcoming SA-3 flight would be useful in predicting C-5 tower temperatures and pressure. Useful information could also be obtained in a single F-1 full scale and model tests.

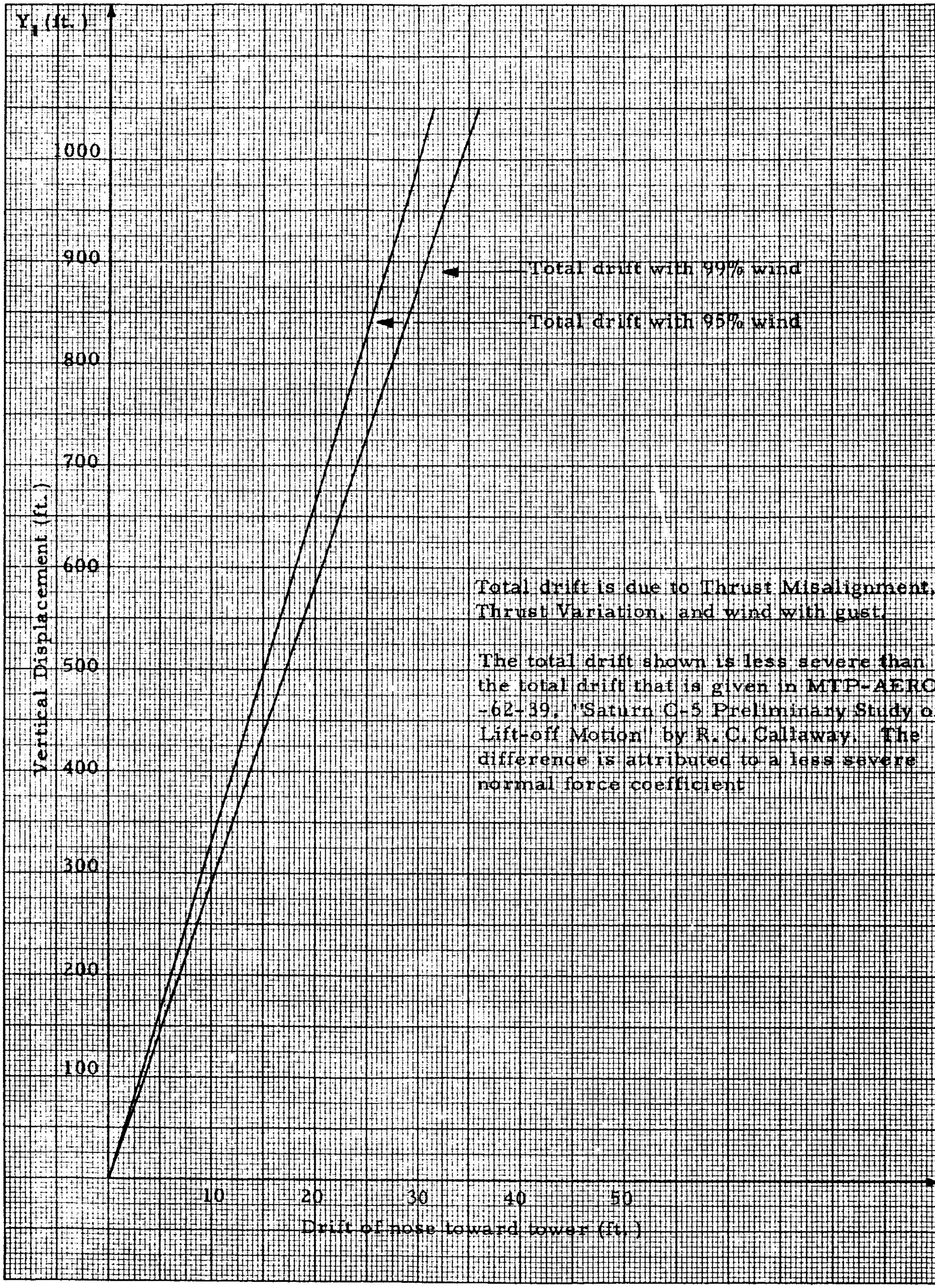
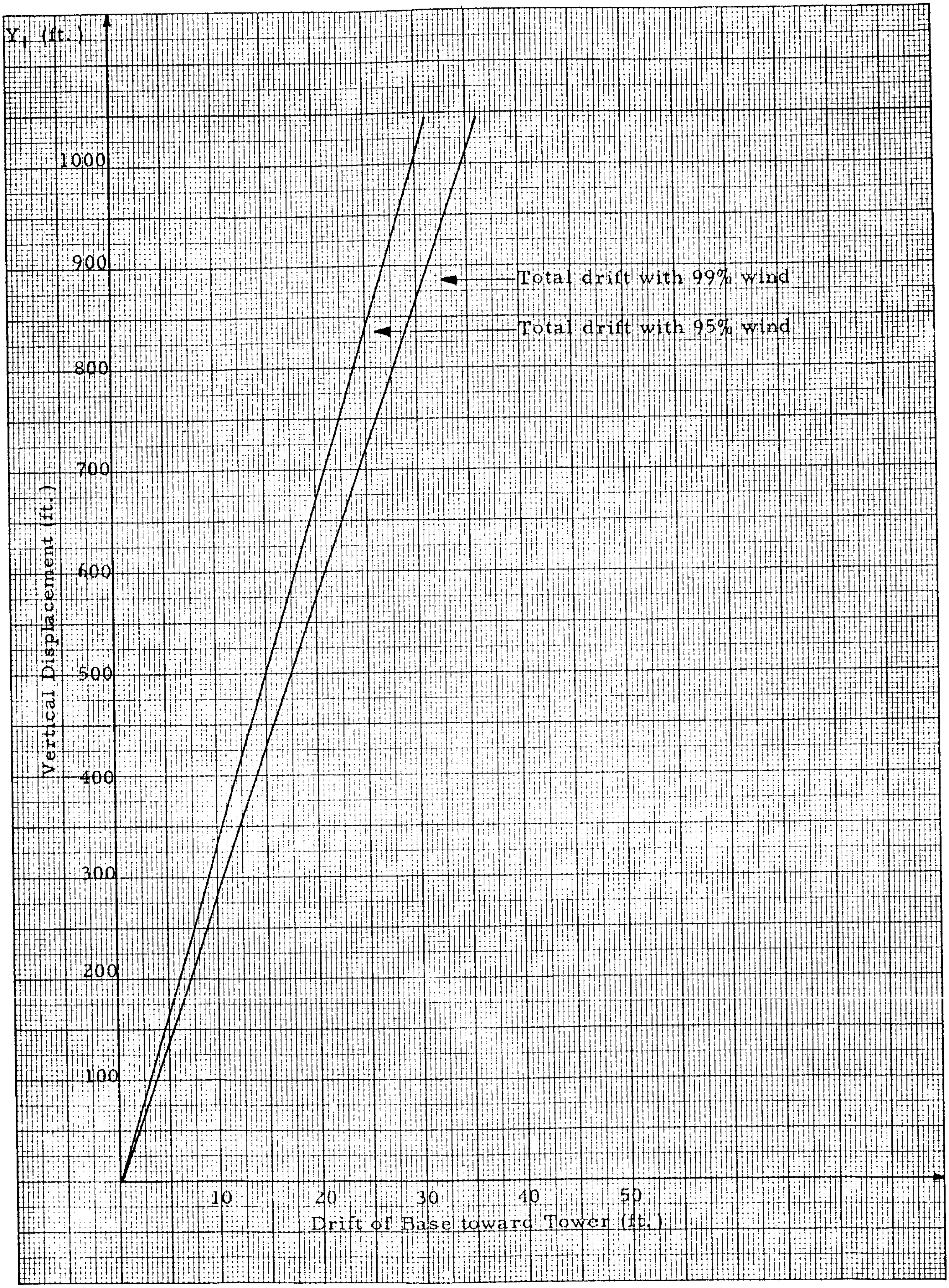

Y₁ (ft.)
1000
900
800
700
600
500
400
300
200
100
10
20
30
40
50
Vertical Displacement (ft.)
Drift of nose toward tower (ft.)
Total drift with 99% wind
Total drift with 95% wind
Total drift is due to Thrust Misalignment, Thrust Variation, and wind with gust.
The total drift shown is less severe than the total drift that is given in MTP-AERO--62-39, "Saturn C-5 Preliminary Study of Lift-off Motion" by R. C. Callaway. The difference is attributed to a less severe normal force coefficient

Figure 1



Y_t (ft.)
Vertical Displacement (ft.)
1000
900
800
700
600
500
400
300
200
100
10
20
30
40
50
Drift of Base toward Tower (ft.)
Total drift with 99% wind
Total drift with 95% wind

Figure 2

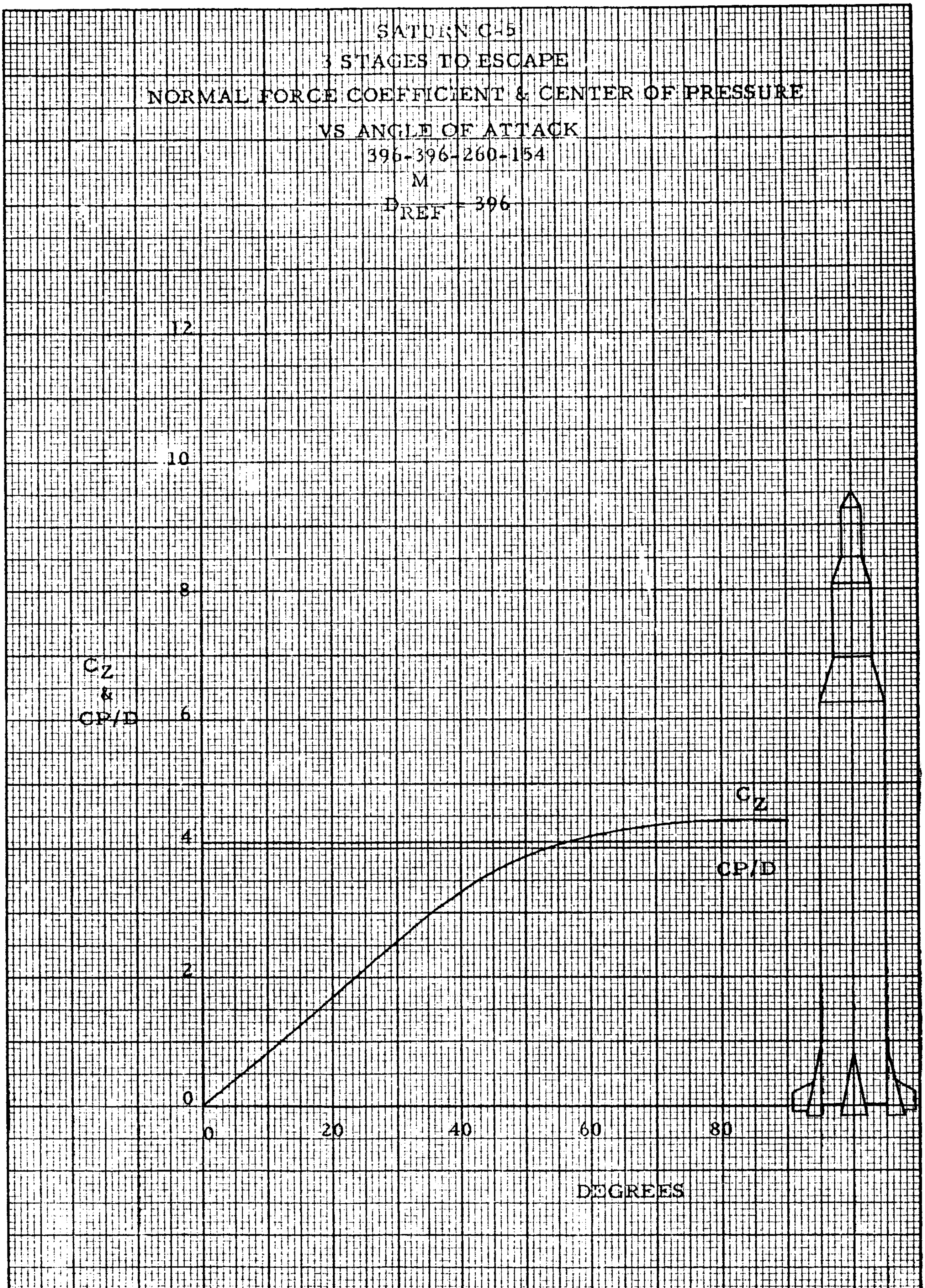
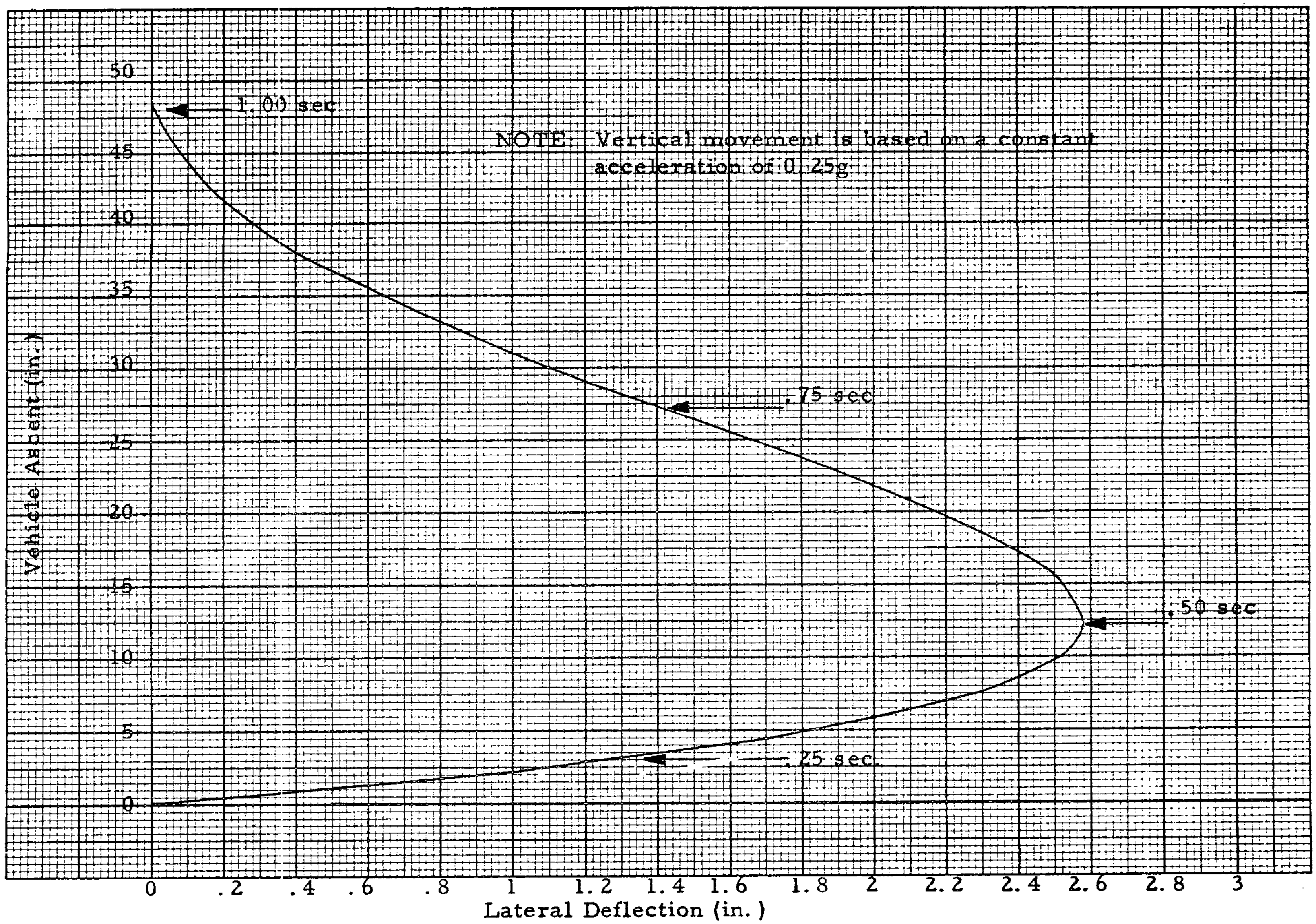

SATURN C-5
3 STAGES TO ESCAPE
NORMAL FORCE COEFFICIENT & CENTER OF PRESSURE
VS ANGLE OF ATTACK
396-396-260-154
M
D REF = 396
12
10
8
C Z
&
CP/D
6
4
2
0
C Z
CP/D
0
20
40
60
80
DEGREES

Figure 3



Saturn C-5 Tanking Mode 2ND Launch - Lateral Deflection At Station 100 vs Vehicle Ascent at 99% Wind Probability

Figure 4.

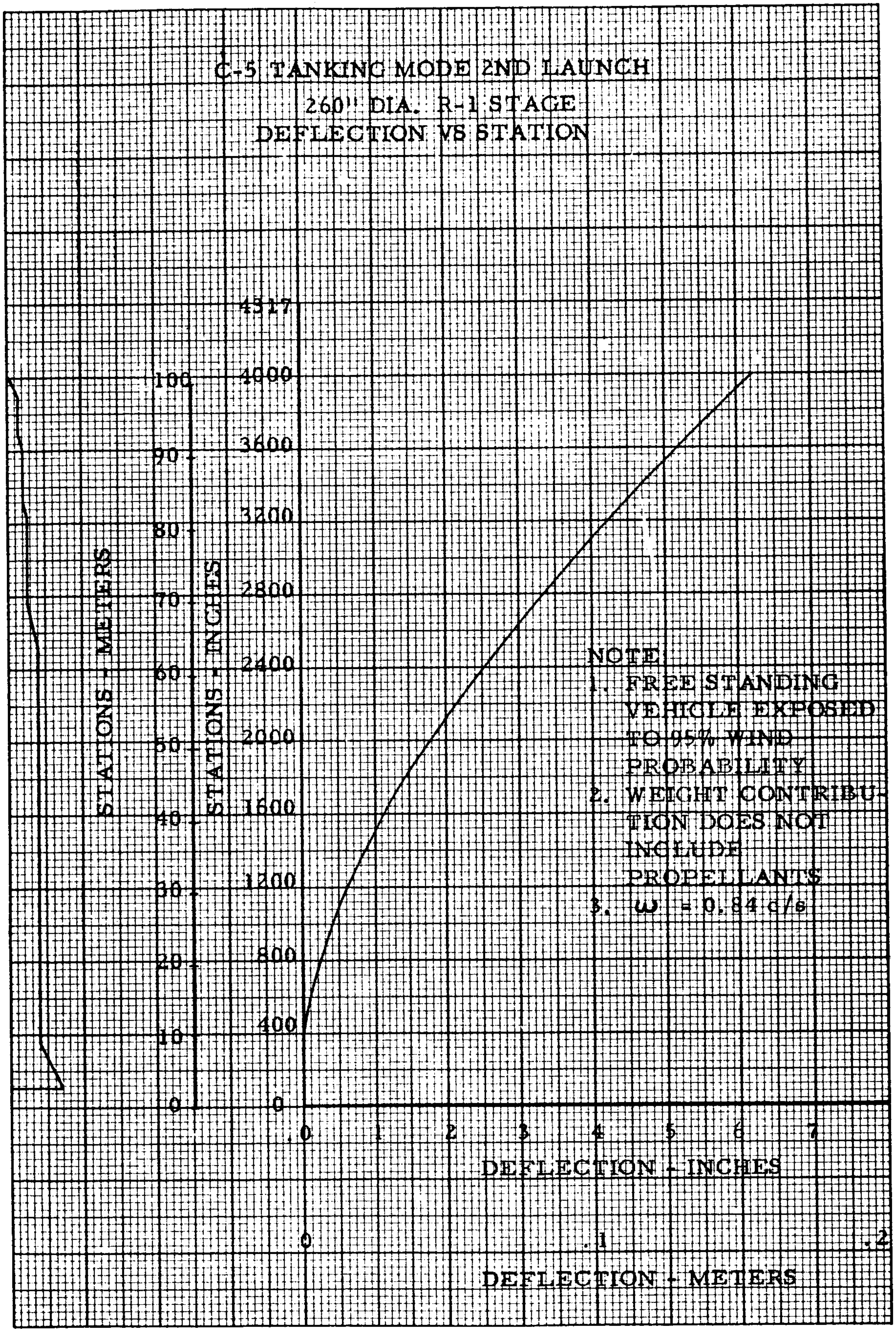
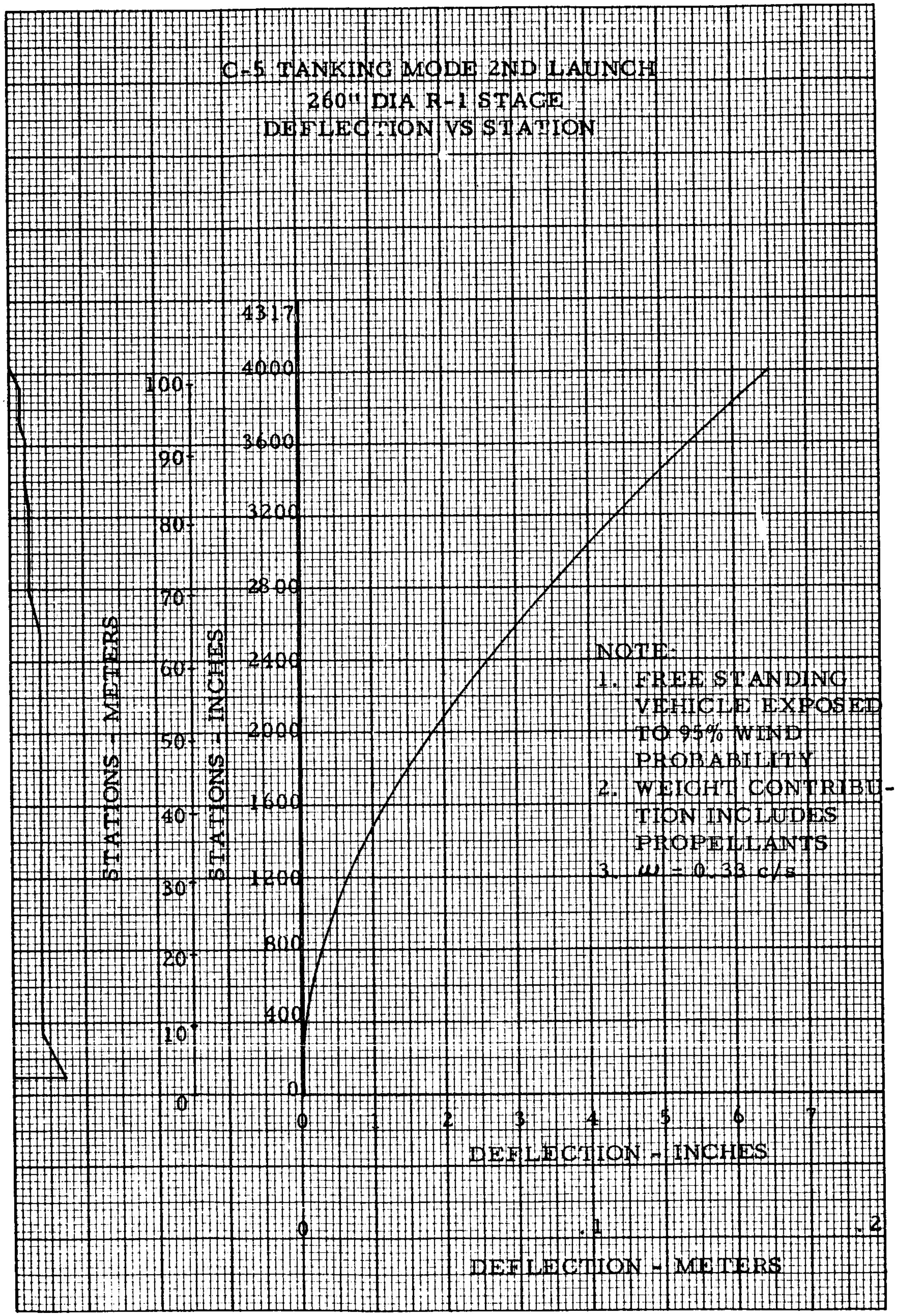

C-5 TANKING MODE 2ND LAUNCH
260" DIA. R-1 STAGE
DEFLECTION VS STATION
STATIONS - METERS
STATIONS - INCHES
4317
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
DEFLECTION - INCHES
0
.1
.2
DEFLECTION - METERS
NOTE:
1. FREE STANDING VEHICLE EXPOSED TO 95% WIND PROBABILITY
2. WEIGHT CONTRIBUTION DOES NOT INCLUDE PROPELLANTS
3. ω = 0.84 c/s

Figure 5



C-5 TANKING MODE 2ND LAUNCH
260" DIA R-1 STAGE
DEFLECTION VS STATION
STATIONS - METERS
STATIONS - INCHES
100
90
80
70
60
50
40
30
20
10
0
4317
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
NOTE:
1. FREE STANDING VEHICLE EXPOSED TO 95% WIND PROBABILITY
2. WEIGHT CONTRIBUTION INCLUDES PROPELLANTS
3. ω = 0.33 c/s
0
1
2
3
4
5
6
7
DEFLECTION - INCHES
0
.1
.2
DEFLECTION - METERS

Figure 6

SATURN C-5 TANKING MODE 2ND LAUNCH
260" DIA. R-1 STAGE
DEFLECTION vs STATION

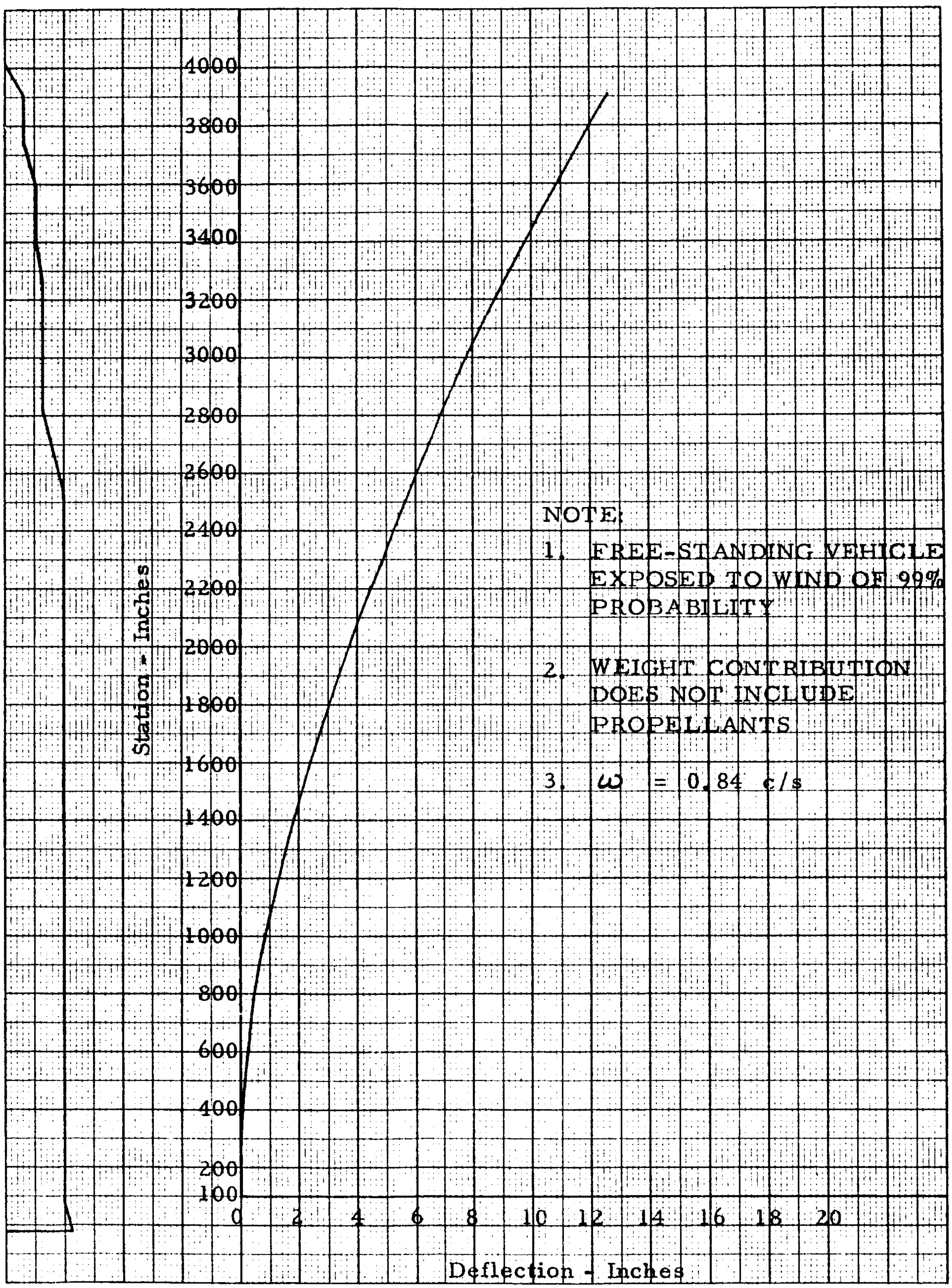


Figure 7

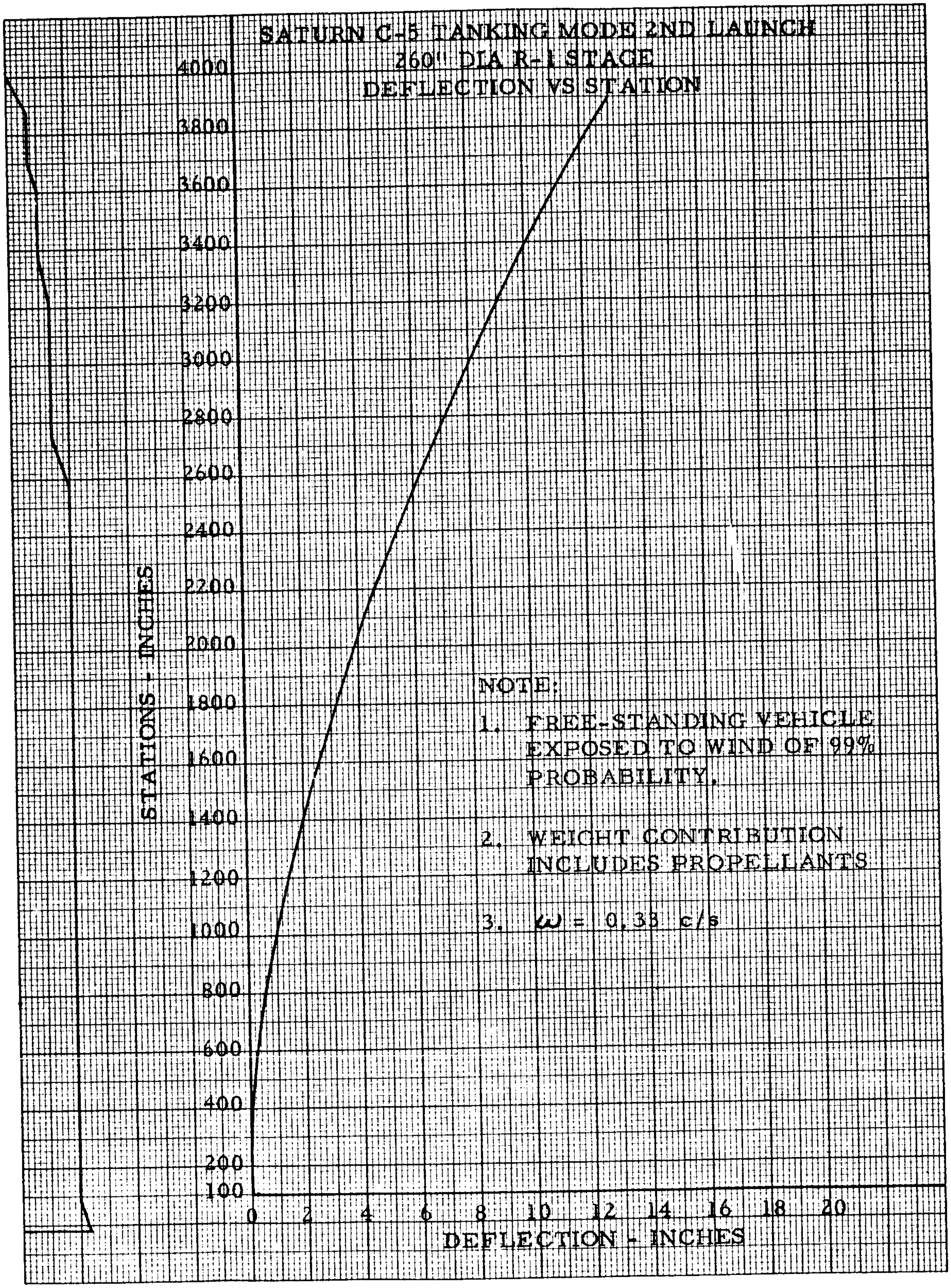

SATURN C-5 TANKING MODE 2ND LAUNCH
260" DIA R-1 STAGE
DEFLECTION VS STATION
STATIONS - INCHES
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
100
0
2
4
6
8
10
12
14
16
18
20
DEFLECTION - INCHES
NOTE:
1. FREE-STANDING VEHICLE EXPOSED TO WIND OF 99% PROBABILITY.
2. WEIGHT CONTRIBUTION INCLUDES PROPELLANTS
3. ω = 0.33 c/s

Figure 8

SATURN C-5 TANKING MODE 2nd LAUNCH
260" DIA. R-1 STAGE
DEFLECTION vs STATION

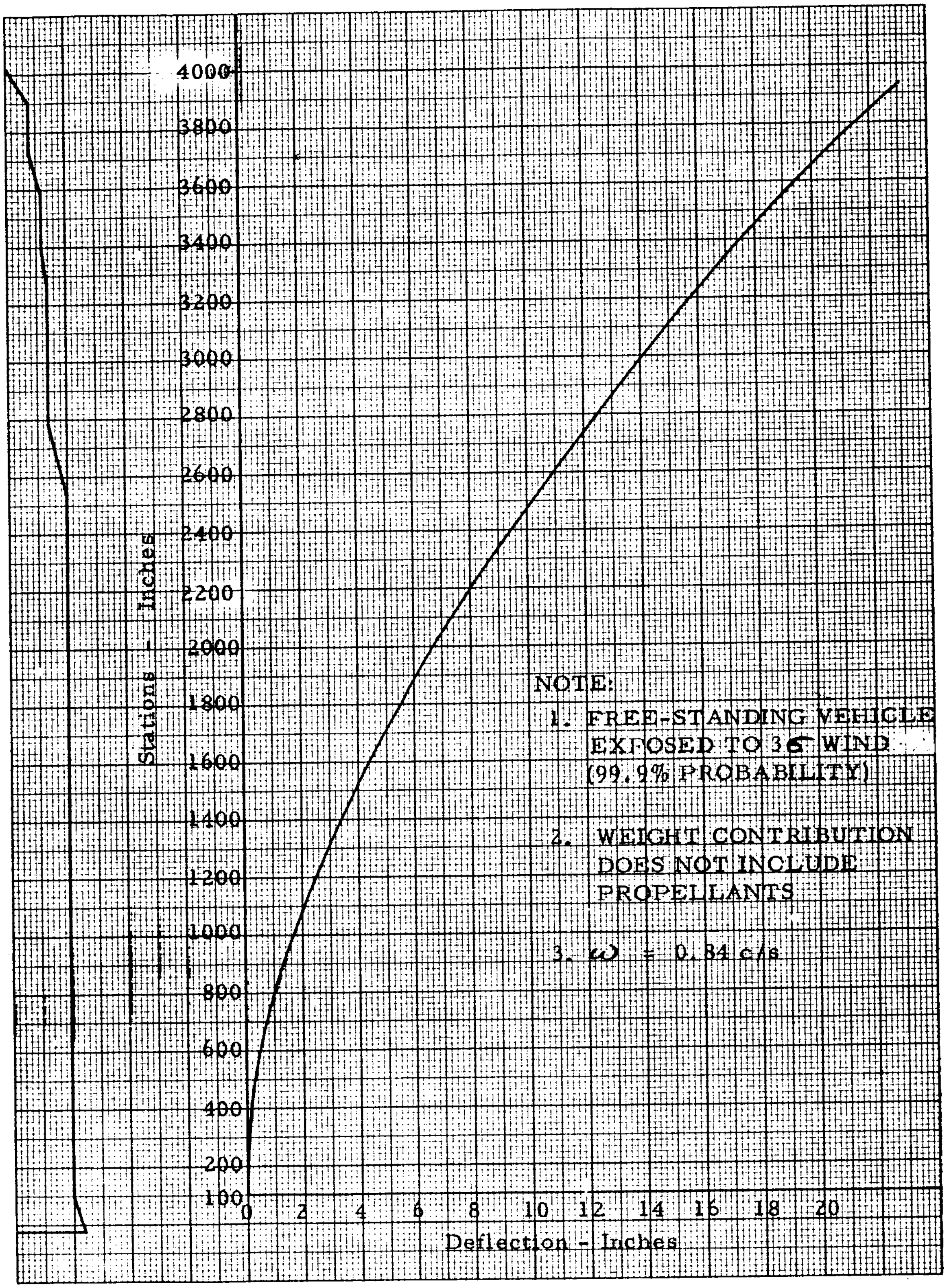


Figure 9

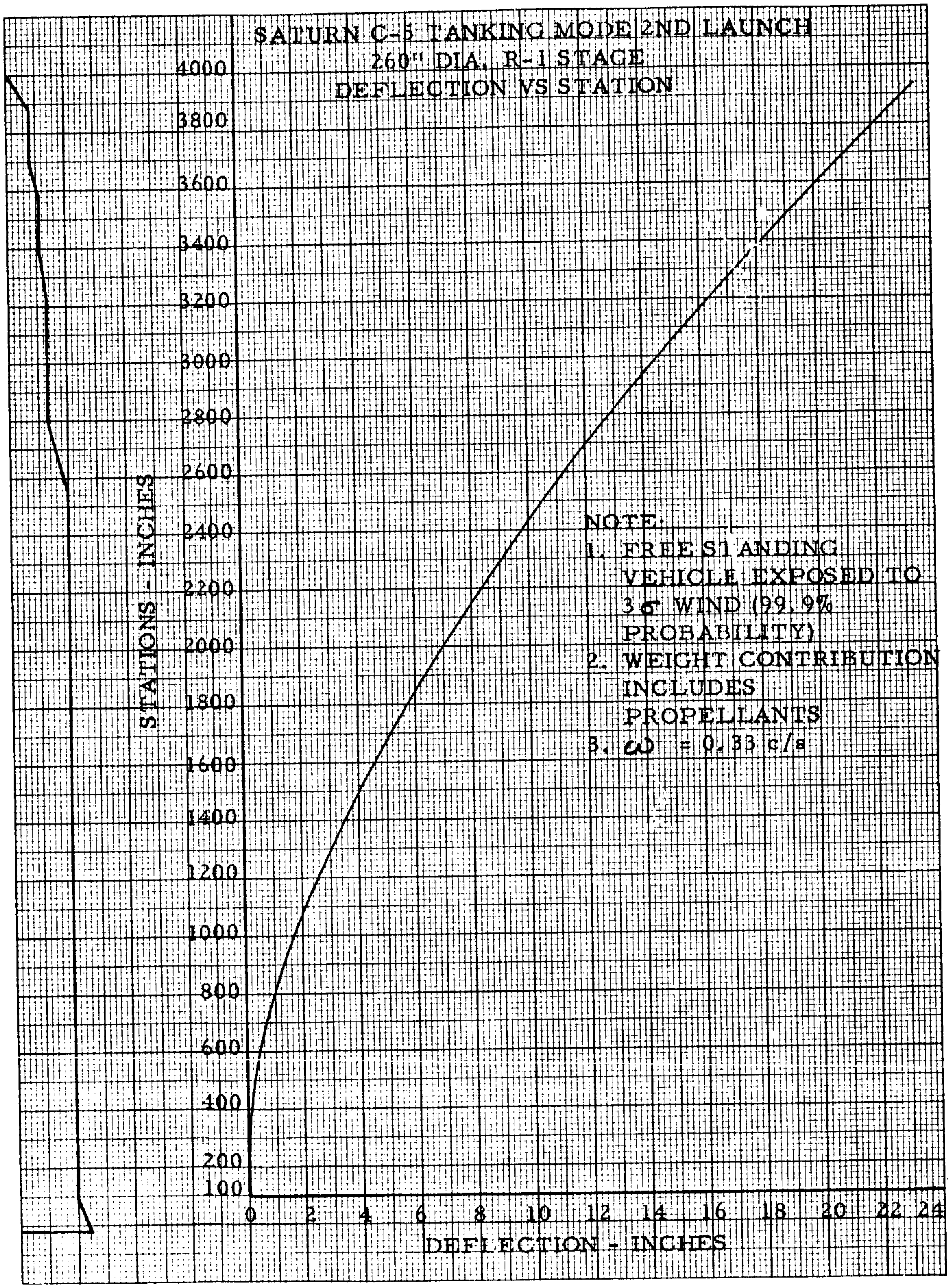

SATURN C-5 TANKING MODE 2ND LAUNCH
260" DIA. R-1 STAGE
DEFLECTION VS STATION
STATIONS - INCHES
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
100
NOTE:
1. FREE STANDING VEHICLE EXPOSED TO 3σ WIND (99.9% PROBABILITY)
2. WEIGHT CONTRIBUTION INCLUDES PROPELLANTS
3. ω = 0.33 c/s
0
2
4
6
8
10
12
14
16
18
20
22
24
DEFLECTION - INCHES

Figure 10

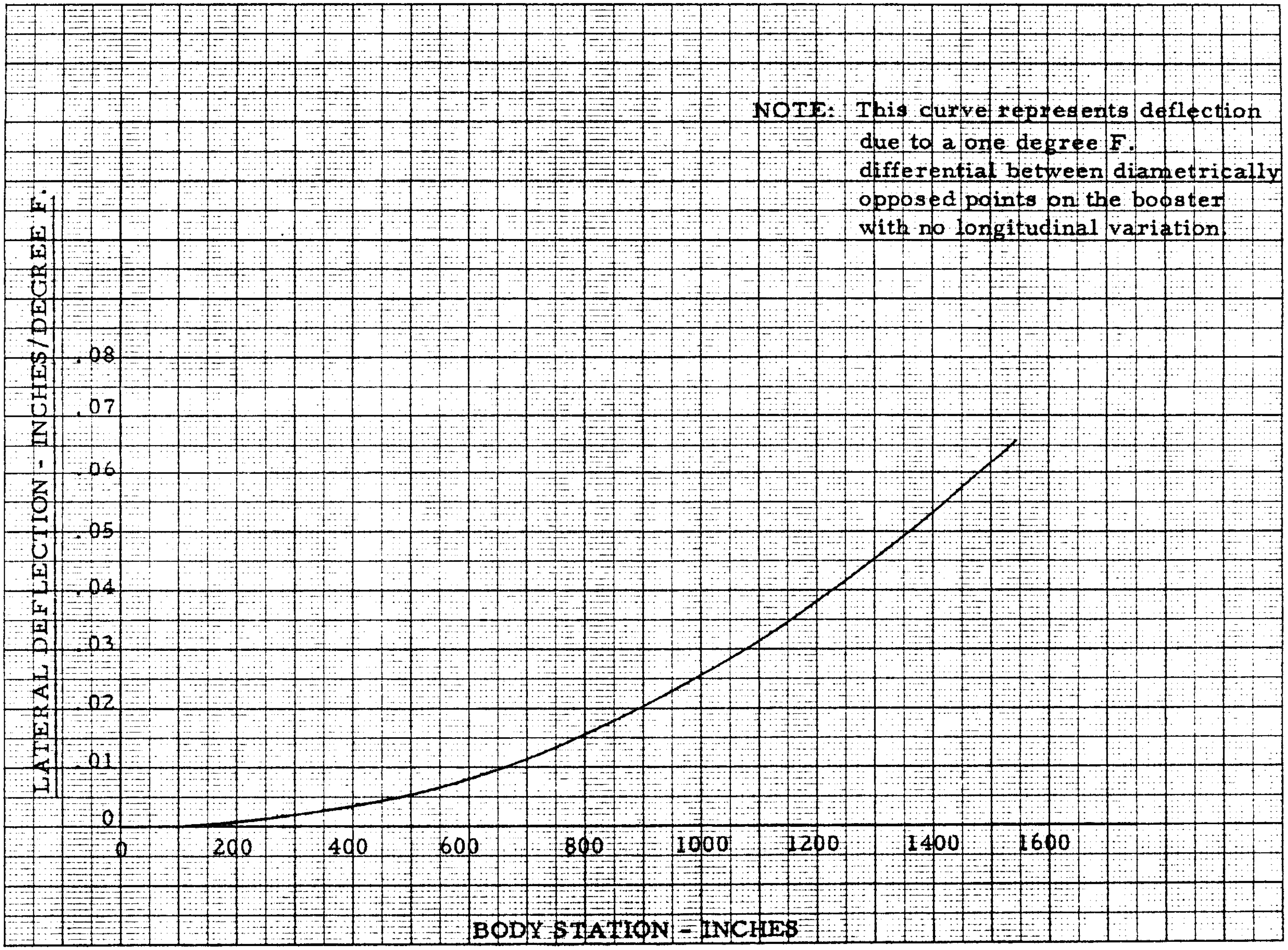


Figure 11. DEFLECTION DUE TO SOLAR WARPAGE

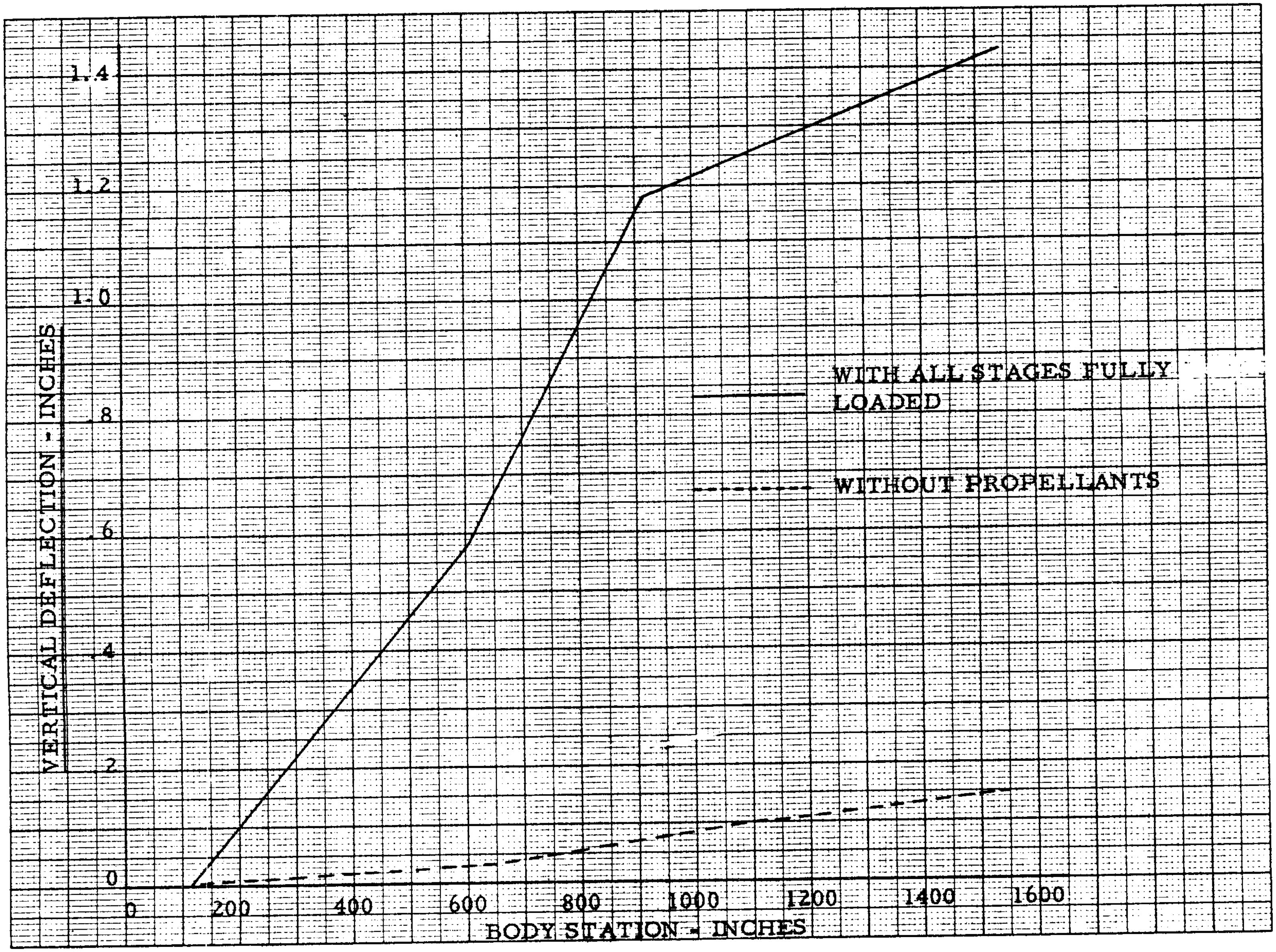


Figure 12. CRUSHING DEFLECTION OF C-5, S-IC STAGE

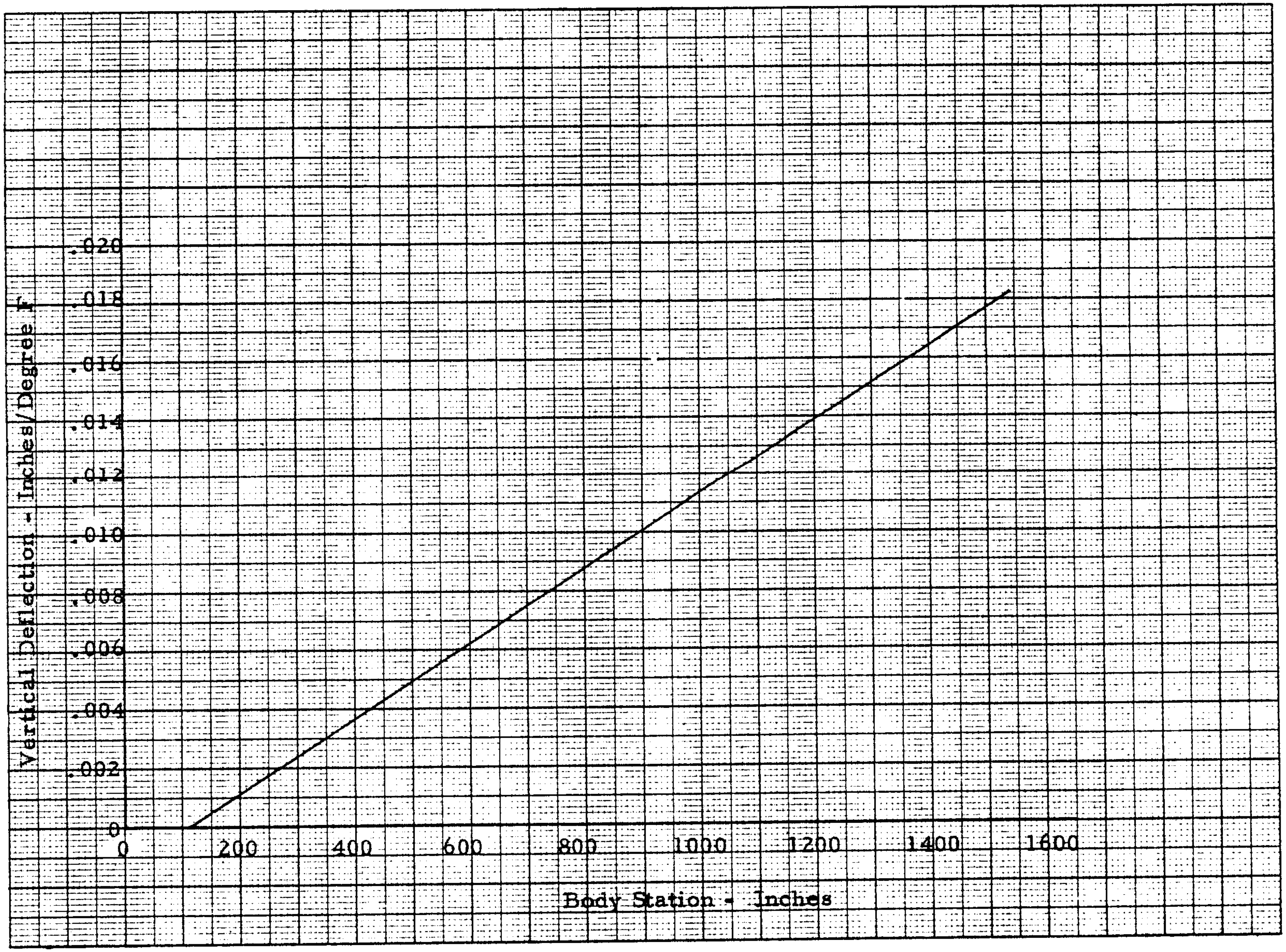


Figure 13. DEFLECTION FOR A UNIFORM TEMPERATURE CHANGE

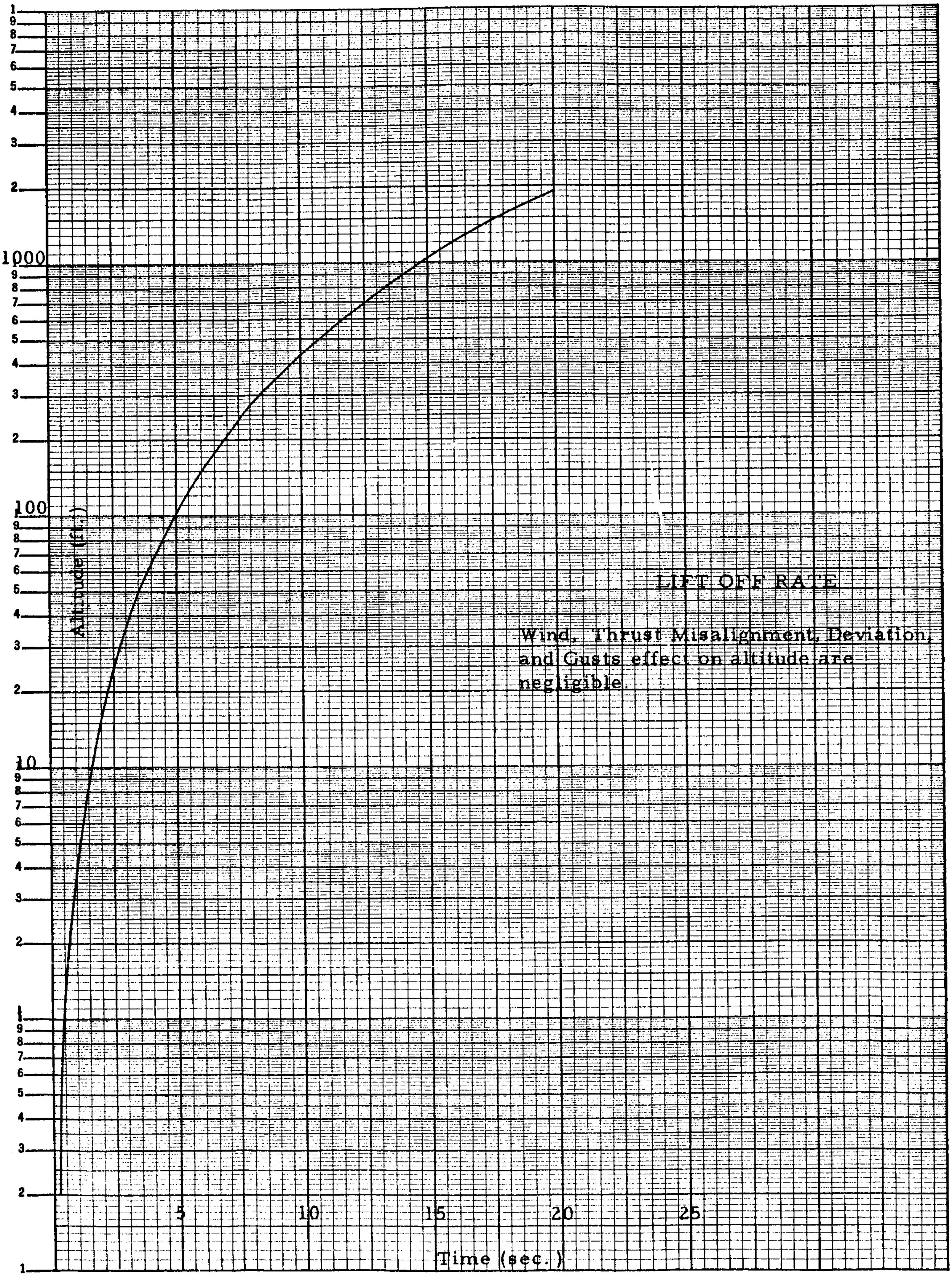

LIFT OFF RATE
Wind, Thrust Misalignment, Deviation, and Gusts effect on altitude are negligible.
Altitude (ft.)
Time (sec.)
1000
100
10
5
10
15
20
25

Figure 14

ENVELOPE OF OVERALL SOUND PRESSURE LEVEL vs VEHICLE ALTITUDE

For Location 120 Feet Above Base of C-5 Umbilical Tower

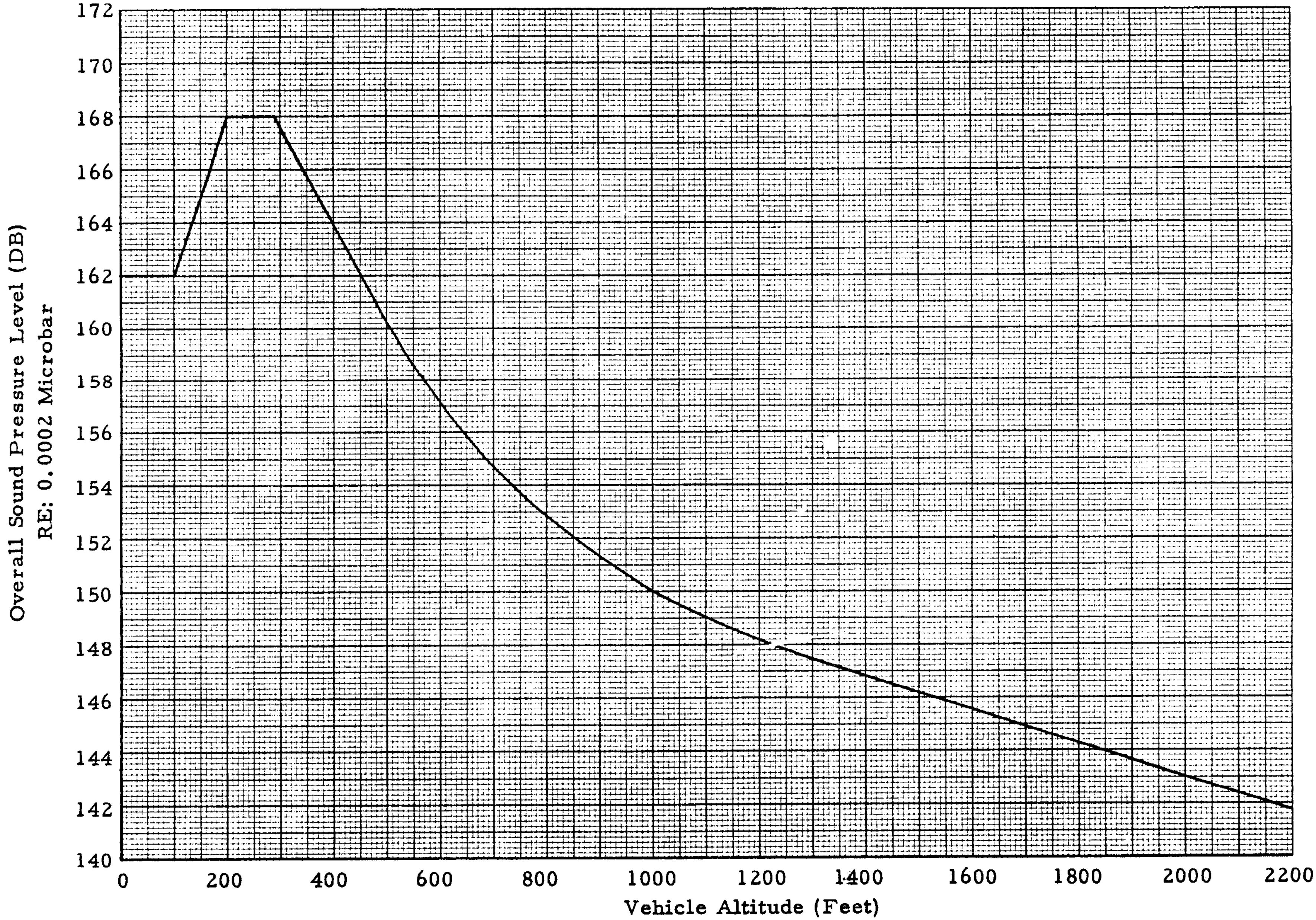


Figure 15

ENVELOPE OF OVERALL SOUND PRESSURE LEVEL vs VEHICLE ALTITUDE

For Location 240 Feet Above Base of C-5 Umbilical Tower

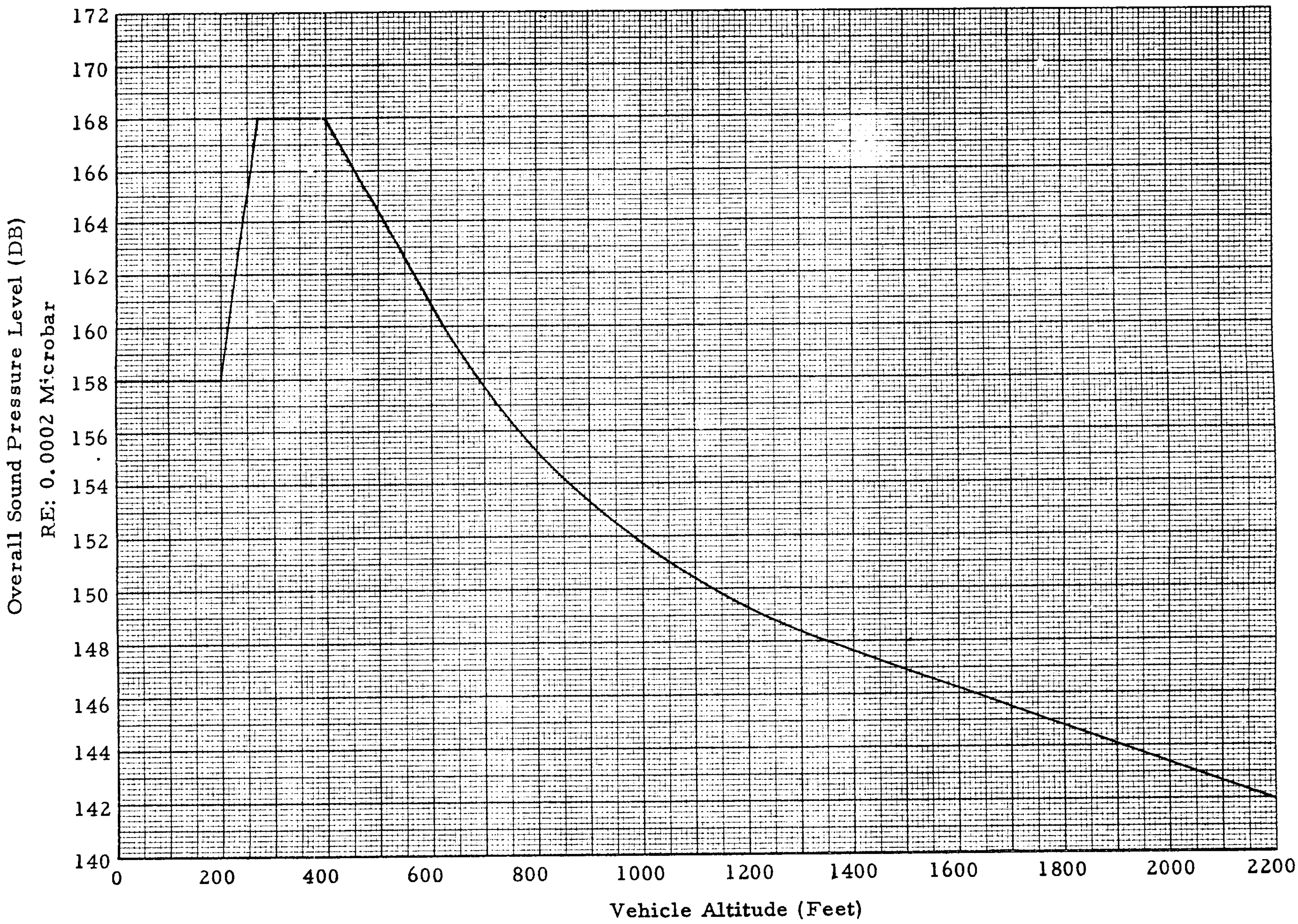


Figure 16

ENVELOPE OF OVERALL SOUND PRESSURE LEVEL vs VEHICLE ALTITUDE
For Location 360 Feet Above Base of C-5 Umbilical Tower

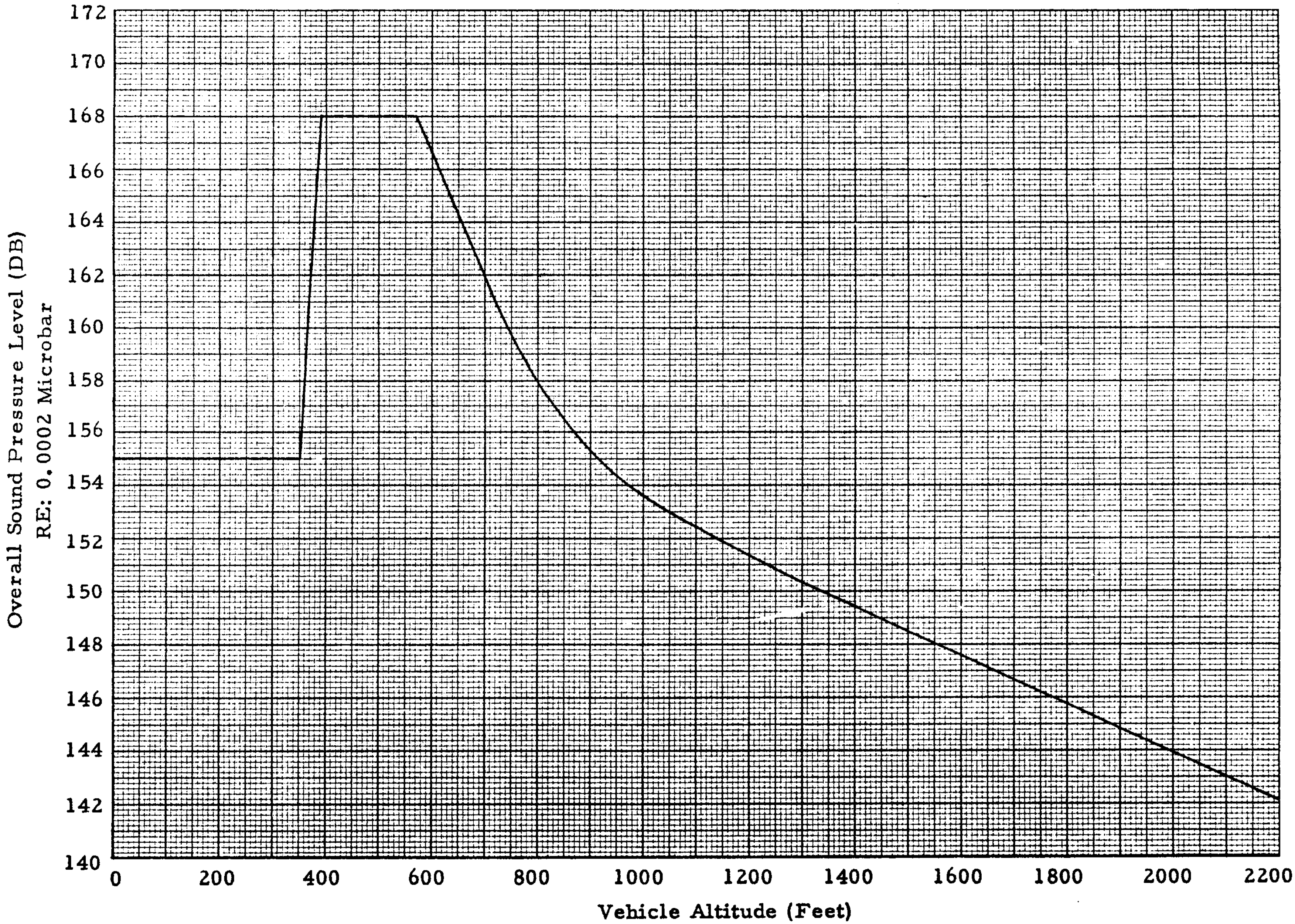
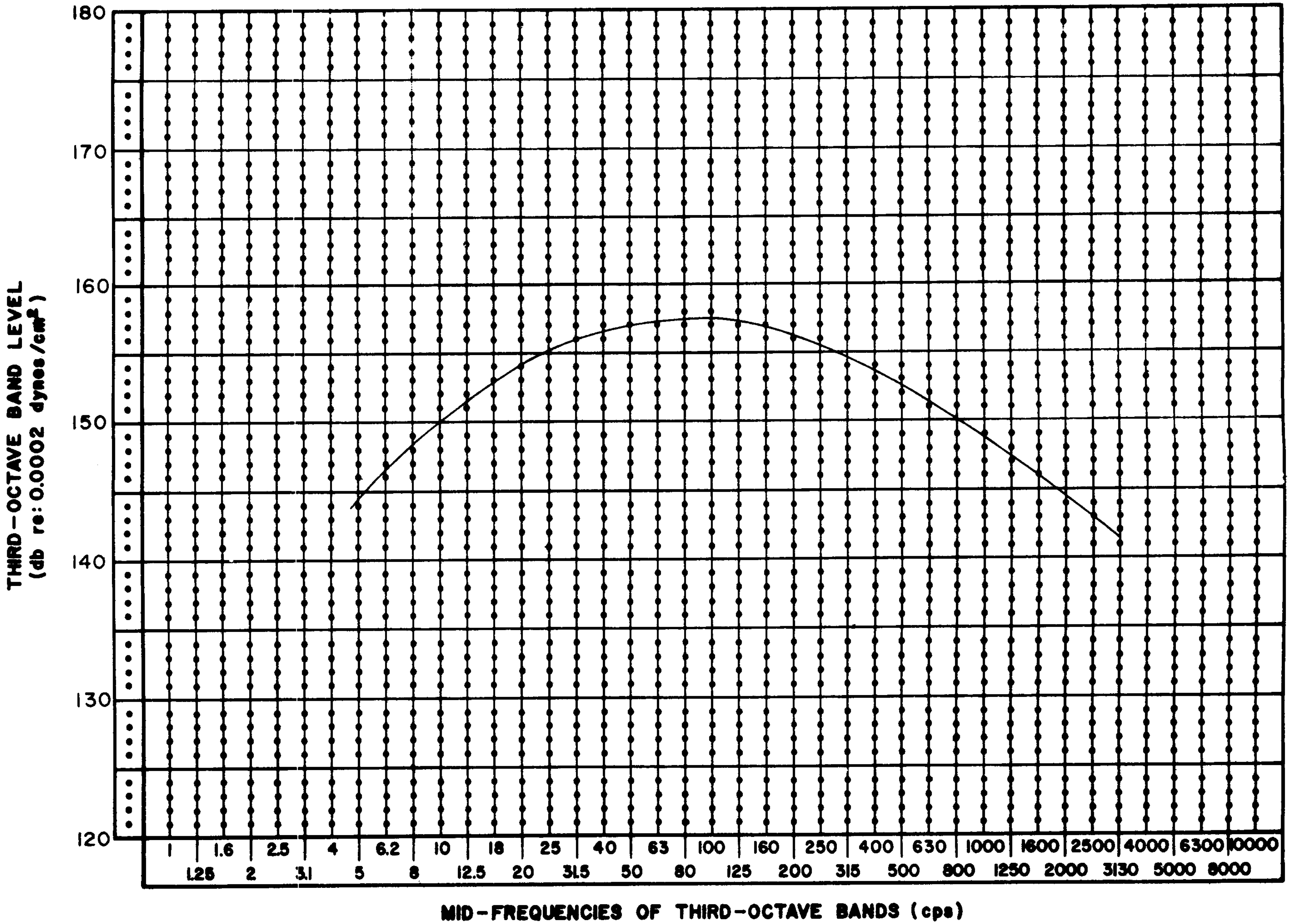
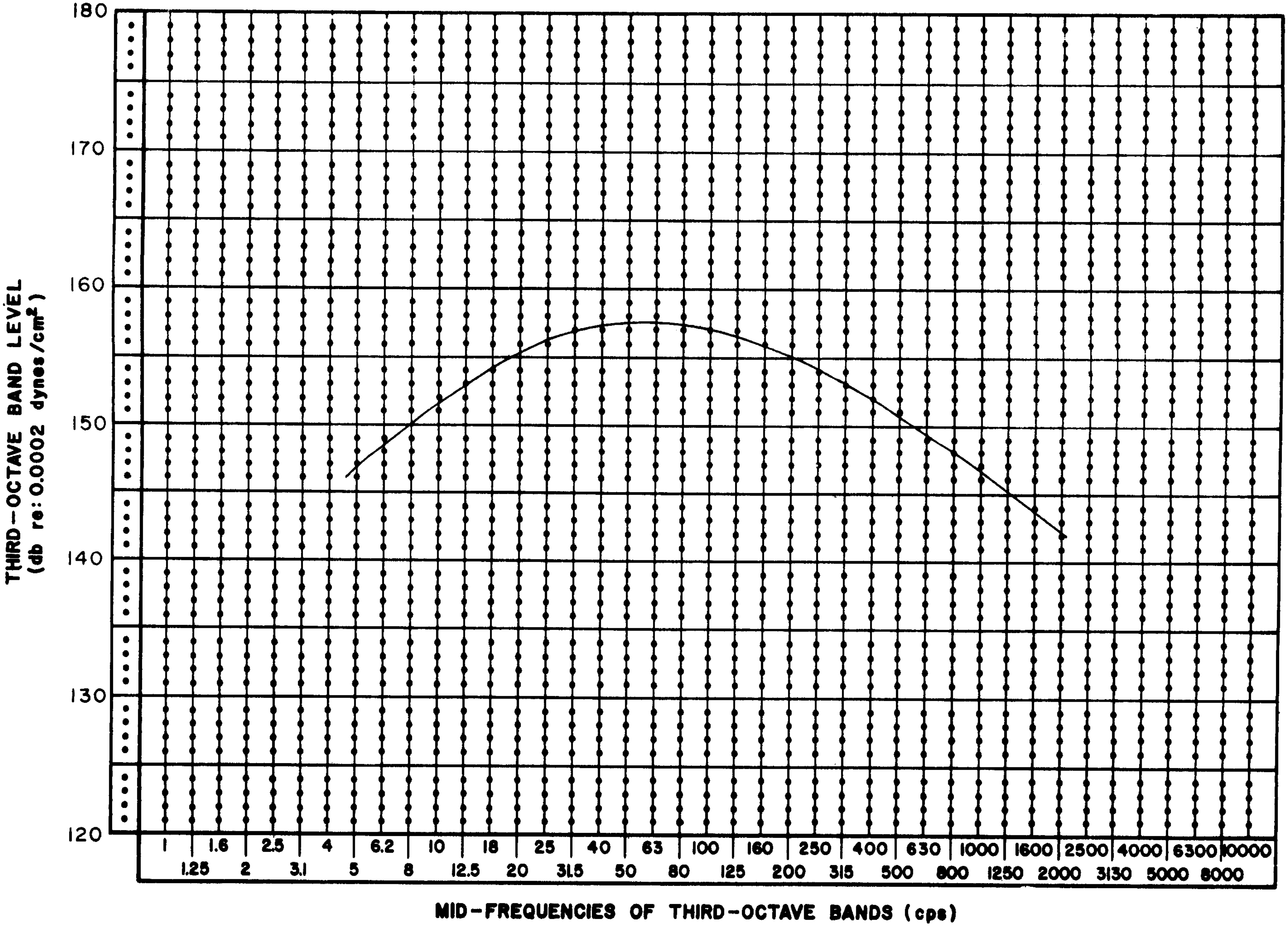


Figure 17



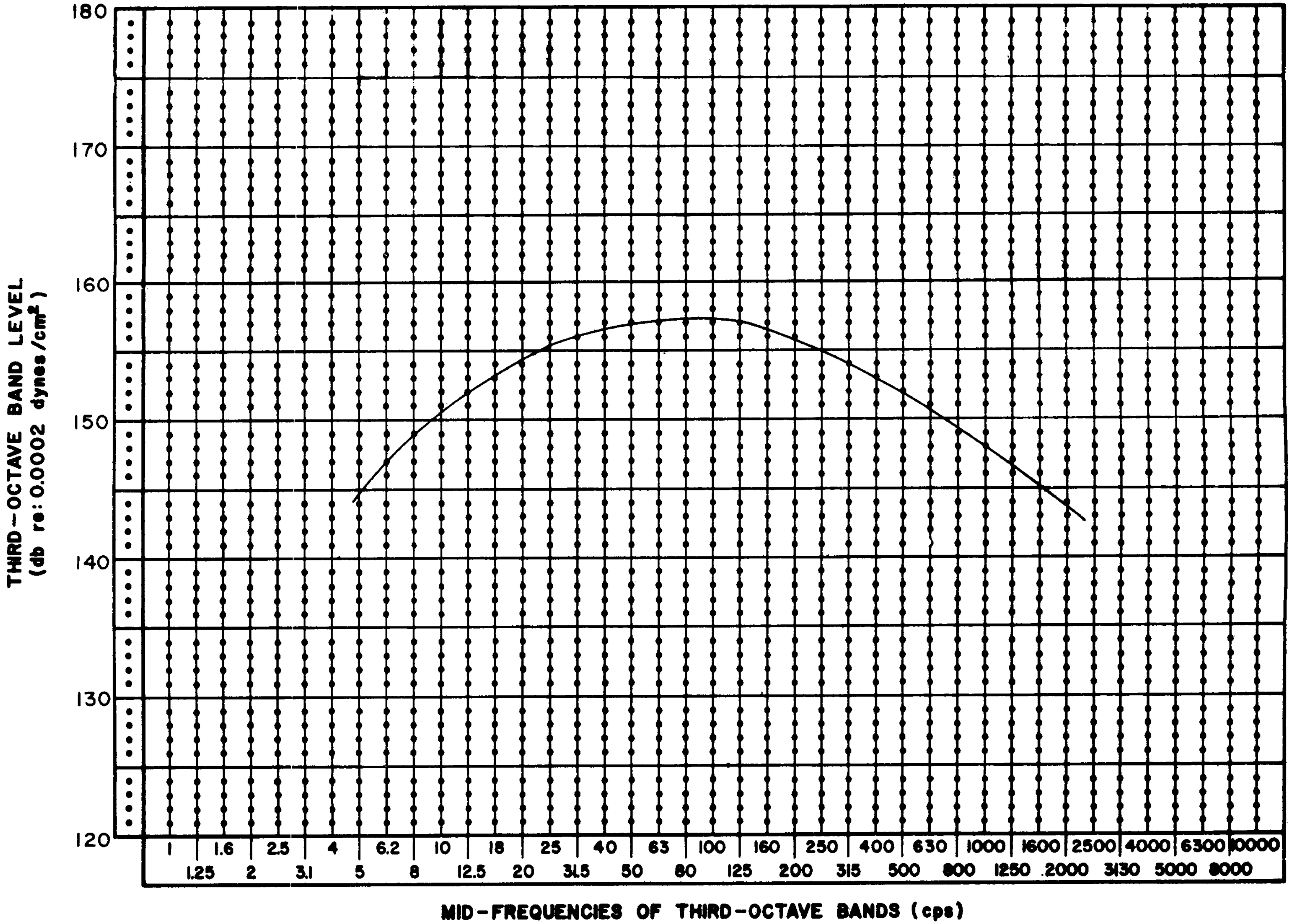
MAXIMUM SPECTRA EXPECTED AT 120 FEET
ABOVE BASE OF C-5 UMBILICAL TOWER

FIGURE 18



MAXIMUM SPECTRA EXPECTED AT 240 FEET
ABOVE BASE OF C-5 UMBILICAL TOWER

FIGURE 19



MAXIMUM SPECTRA EXPECTED AT 360 FEET
ABOVE BASE OF C-5 UMBILICAL TOWER

FIGURE 20

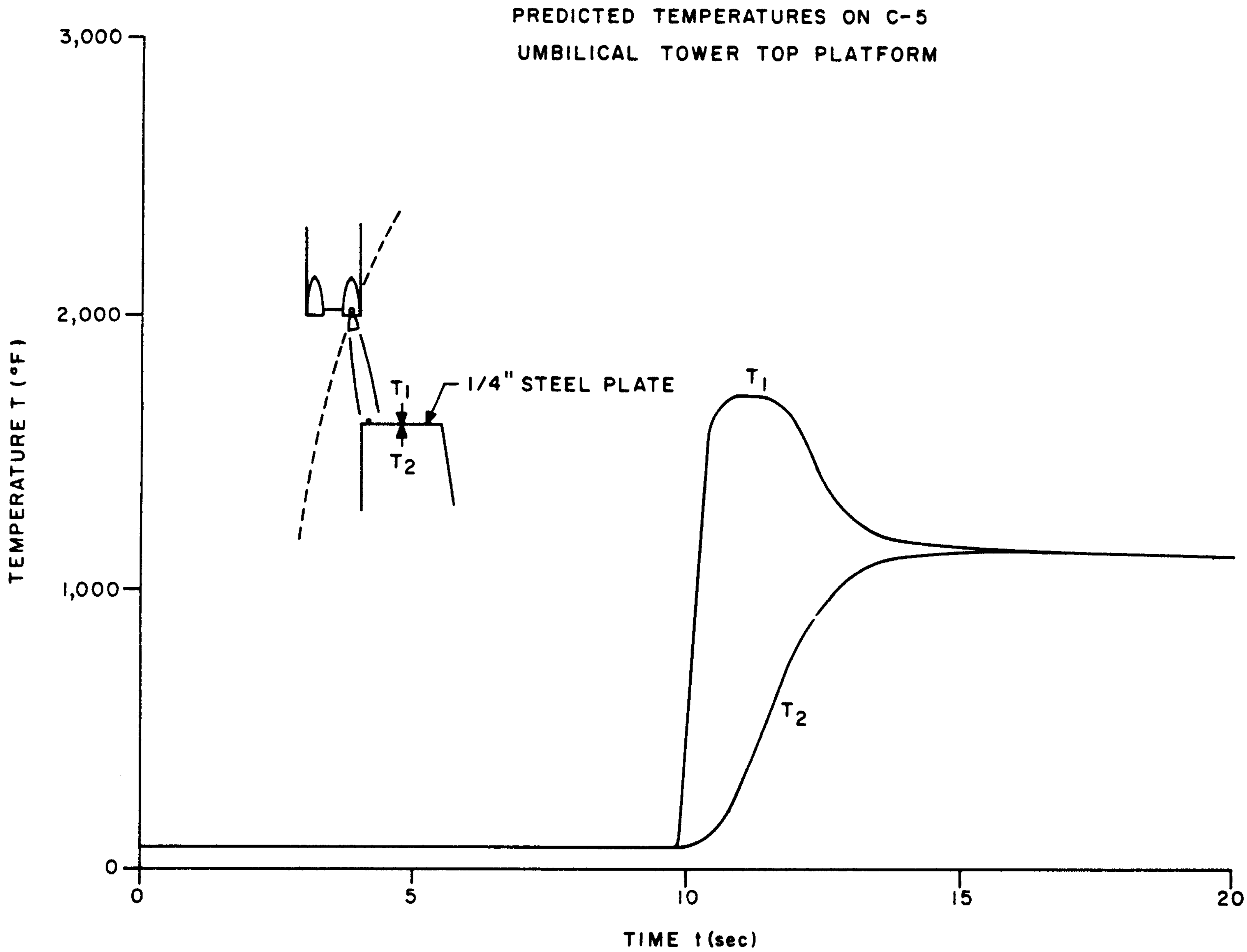

PREDICTED TEMPERATURES ON C-5
UMBILICAL TOWER TOP PLATFORM
3,000
2,000
1,000
0
TEMPERATURE T (°F)
1/4" STEEL PLATE
T_1
T_2
T_1
T_2
0
5
10
15
20
TIME t (sec)

FIGURE 21

PREDICTED TEMPERATURES ON C-5 UMBILICAL TOWER TOP PLATFORM

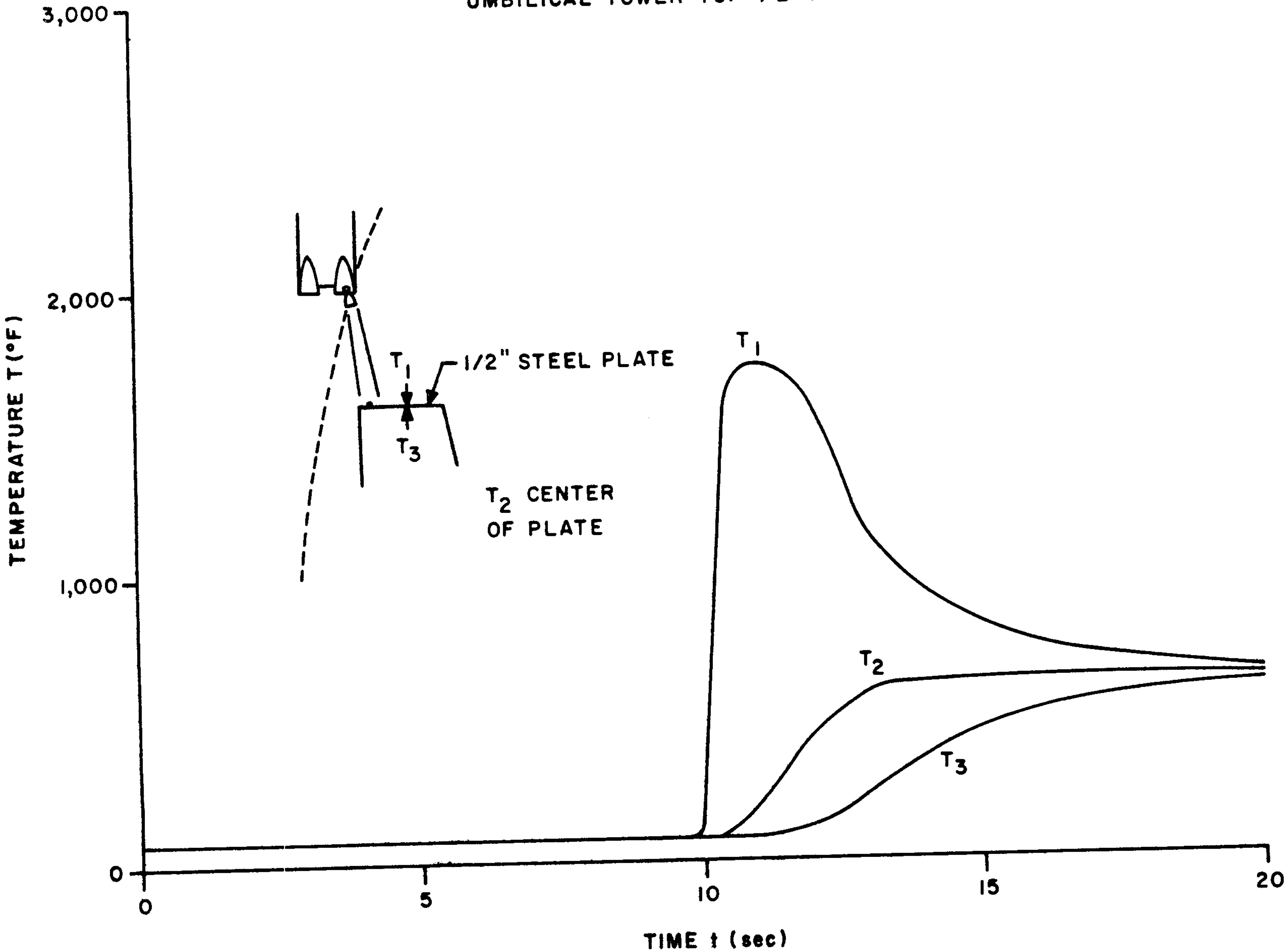


FIGURE 22

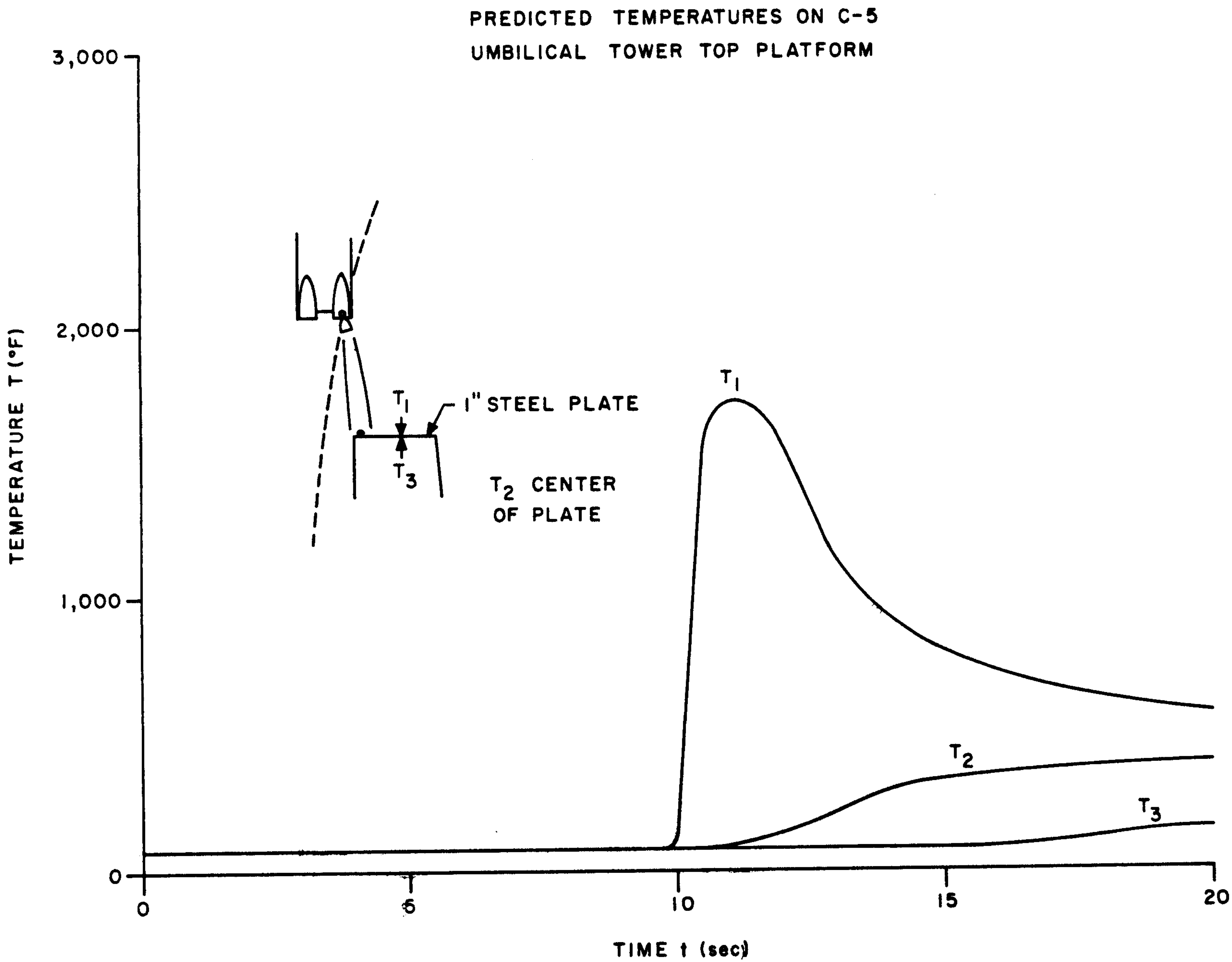

PREDICTED TEMPERATURES ON C-5
UMBILICAL TOWER TOP PLATFORM
3,000
2,000
1,000
0
TEMPERATURE T (°F)
T_1
1" STEEL PLATE
T_3
T_2 CENTER
OF PLATE
T_1
T_2
T_3
0
5
10
15
20
TIME t (sec)

FIGURE 23

PREDICTED TEMPERATURES ON VERTICAL BEAM
ONE FOOT FROM TOP OF C-5 UMBILICAL TOWER

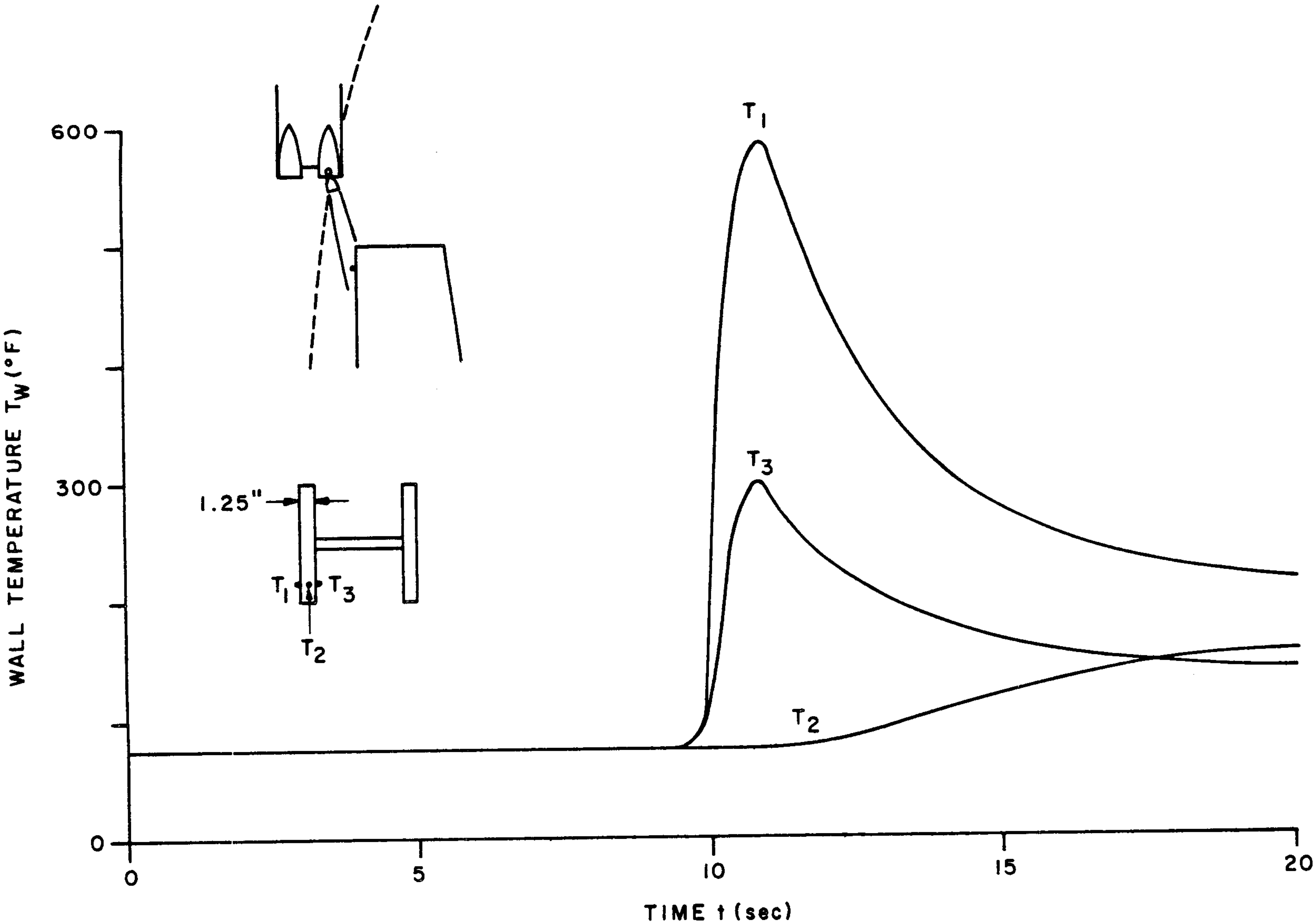


FIGURE 24

PREDICTED TEMPERATURES ON VERTICAL BEAM
ONE FOOT FROM TOP OF C-5 UMBILICAL TOWER

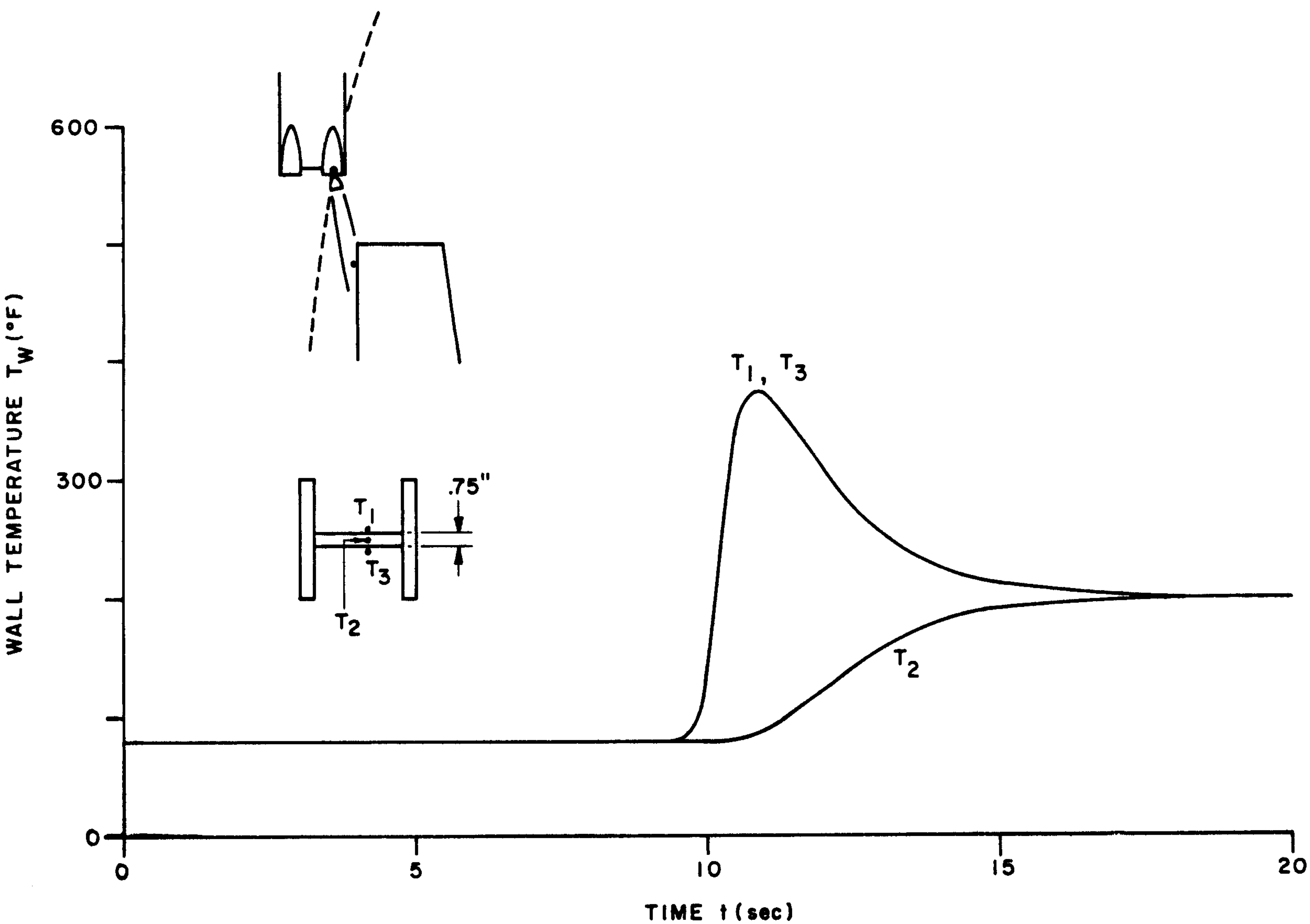


FIGURE 25

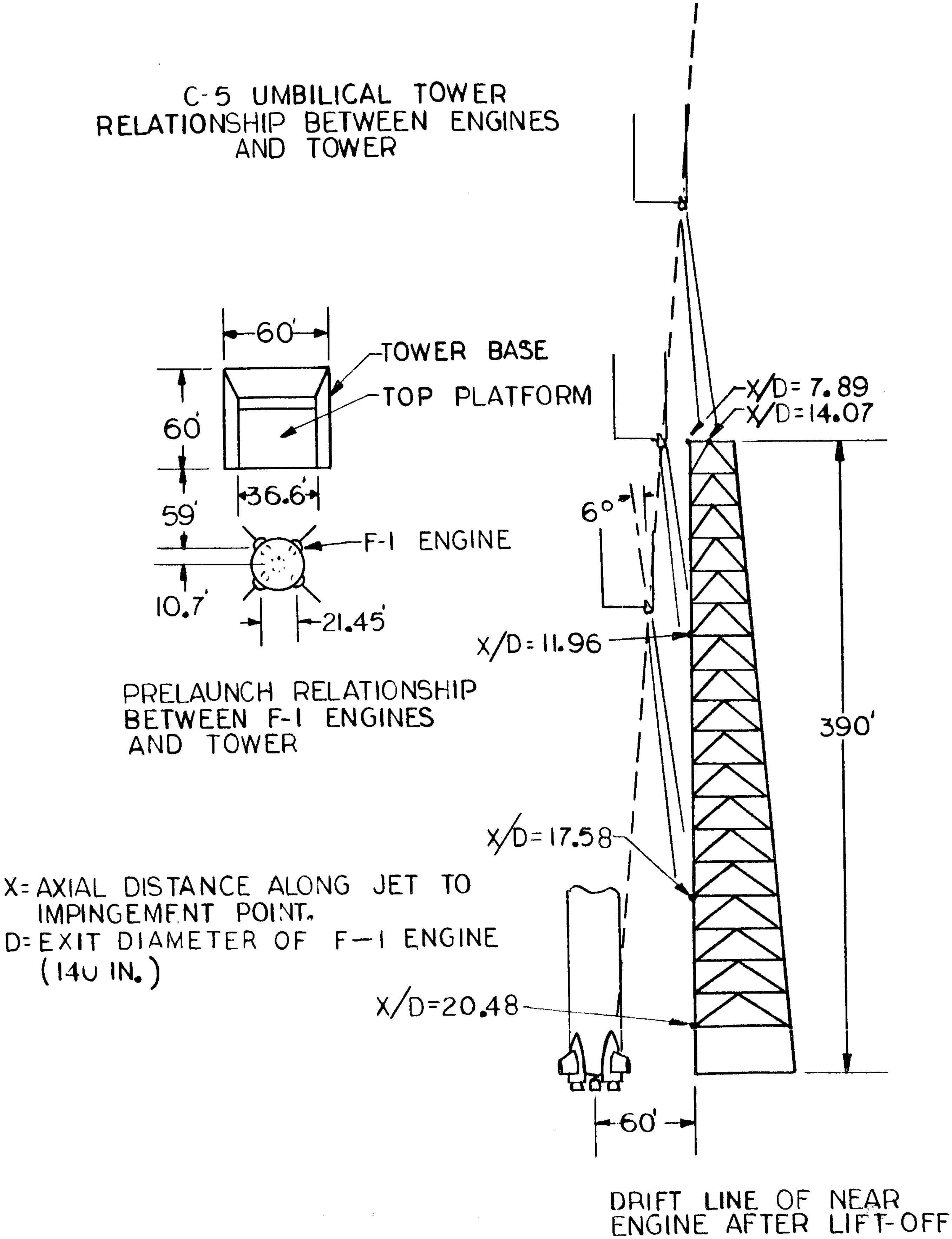

C-5 UMBILICAL TOWER
RELATIONSHIP BETWEEN ENGINES
AND TOWER
60'
TOWER BASE
TOP PLATFORM
60'
36.6'
59'
F-1 ENGINE
10.7'
21.45'
PRELAUNCH RELATIONSHIP
BETWEEN F-1 ENGINES
AND TOWER
X/D = 7.89
X/D = 14.07
6°
X/D = 11.96
390'
X/D = 17.58
X/D = 20.48
60'
DRIFT LINE OF NEAR
ENGINE AFTER LIFT-OFF
X= AXIAL DISTANCE ALONG JET TO
IMPINGEMENT POINT.
D= EXIT DIAMETER OF F-1 ENGINE
(140 IN.)

FIG. 26

In view of the latest information received on blast temperatures, umbilical arm and rigging survival are questionable. Further tests will determine if reuse of the arms is possible. Three considerations regarding arm survival are as follows:

1. Arms and rigging may be considered expendible; if so, a sufficient number of spares would be stocked to refurbish the tower for future launches.

2. Arms and/or rigging may be reused if a suitable protective coating can be applied to the structure and components. Such coatings have been used in previous launches.

3. Arms may be reused if another material, possibly steel, is used for structural framing. This would require redesign of the arms. In this case, the rigging would still be considered expendible.

Concept Study Report
Launch Complex 39 Umbilical Arms
LTIR-2-DE-62-2
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